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CONTENTS

PROCEEDINGS OF THE INSTITUTE

Report of Visit to Finland 217
The Iron and Steel Industry of Finland by Sir Charles F. Goodeve 219

THE IRON AND STEEL INSTITUTE

An Investigation of Reheating Furnace Design and Performance by F. A. Gray and S. H. Brooks 223
A Statistical Study of the Creep and Fatigue Properties of a Precision-Cast High-Temperature Alloy by G. T. Harris and H. C. Child 284
Measurement of Case Depth after Carburization by J. Taylor 291

DISCUSSION ON PAPERS

Correspondence on the Length of Oil and Gas Flames 222

AFFILIATED LOCAL SOCIETIES

The Operation of Soaking Pits by J. Dodd 297

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Improvements in the Absorptiometric Determination of Tungsten by the Methods of Analysis Committee 267
The Problem of Rupture of the Billet in the Continuous Casting of Steel by J. Savage and W. H. Pritchard 269
Chromium-Oxygen Equilibrium in Liquid Iron by E. T. Turkdogan 278

IRON AND STEEL ENGINEERS GROUP

Melting-Shop Reconstruction at the Normanby Park Steel Works. John Lysaght's Scunthorpe Works Ltd. by J. A. Peacock 301

NEWS

The Iron and Steel Institute ... 306
News of Members 307
Contributors to the Journal ... 307
British Iron and Steel Research Association 308
Institute of Metals 308
Education 308
News of Science and Industry 309
Diary 310
Translation Service 310

ABSTRACTS

Contents 311
Abstracts 311-334
Book Notices 334-335
New Publications ... 335-336

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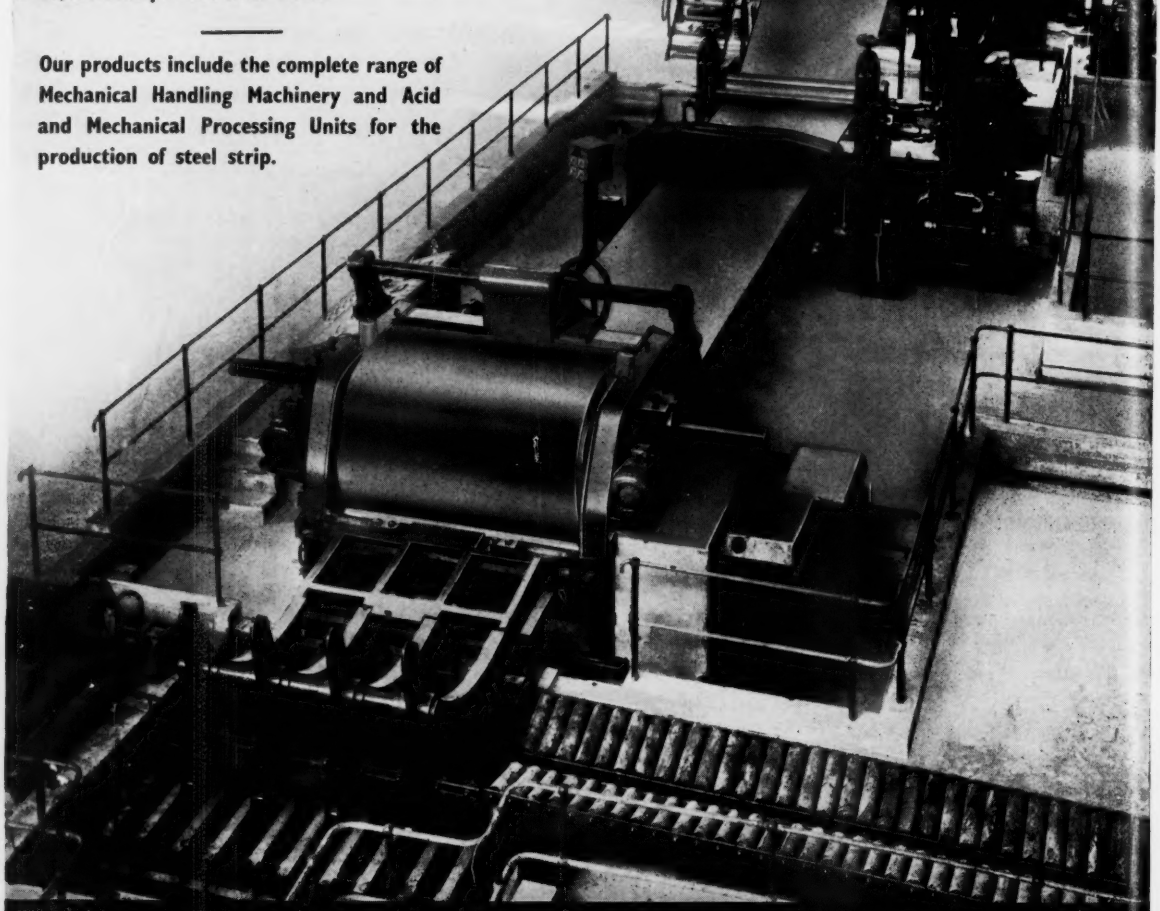

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BERNDT GRÖNBLOM

BERNDT GUSTAF GRÖNBLOM was born at Åbo, Finland, in 1885, and graduated from the Institute of Technology of Finland in 1908.

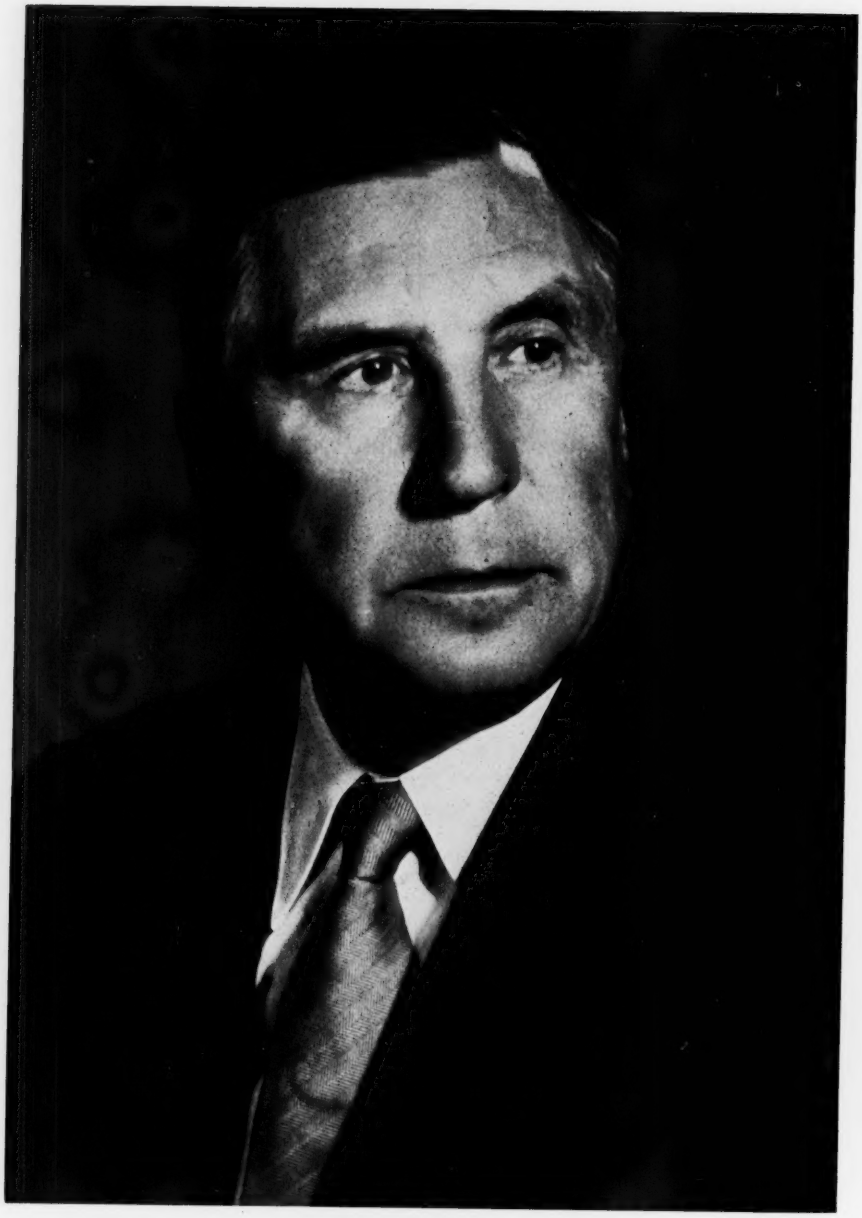
Mr. Grönblom's first industrial experience was in the oil industry. After study in Germany and the United Kingdom and service in Baku, he founded Finska Oljefabriken E. Grönblom in 1912. He subsequently held the position of Managing Director of the Company until 1930, when it was sold to the Royal Dutch Shell and Standard Oil Companies.

In 1915 Mr. Grönblom founded Elektrometallurgiska Aktiebolaget, a company at Vuoksenniska engaged initially in the production of ferro-silicon, and later expanded to produce other ferro-alloys as well as calcium-carbide and mechanical pulp. In 1934 the name of the company was altered to Osakeyhtiö Vuoksenniska Aktiebolaget; a year later the Imatra Steel Works was founded as a subsidiary, and in 1943 it began to operate a blast-furnace at Åbo. Since 1940 the Company has also had an interest in underground ore mining. Mr. Grönblom is Chairman of the Board and Managing Director of the Company.

Mr. Grönblom participated in Finland's war of liberation in 1918; during the war he was commissioned and held a front-line command. He was attached to the Finnish Legation in Berlin in 1918 and 1919, and in 1920 he represented Finland at the Baltic States' Conference in Riga. He was entrusted with government commissions in Moscow, Rome, and Brussels from 1939 to 1941, and he acted as an economic expert during the negotiations for an Armistice between Finland and the Soviet Union in 1944.

Mr. Grönblom is a member of the Board of the following companies and institutions: AB Nordiska Föreningsbanken, Oy Grönblom AB, The Association of Finnish Metal Industries, and The Association of Mining Engineers. He is also a member of the Delegation of the Foundation of Åbo Akademii (Swedish University of Åbo), and of the Swedish Scientific Central Council of Finland, and an honorary member of the Technical Association of Finland. He was made a Councillor of Mines in 1918, and was awarded the honorary degree of Ph.D. in 1948. He is a holder of the Liberty Cross, 1st, 2nd and 3rd Class, is a Commander I and II of the White Rose of Finland, and has been awarded the Grand Cross of the Order of Finland's Lion.

Mr. Grönblom became a Member of The Iron and Steel Institute in 1947, and was nominated an Honorary Vice-President in 1954.



Berndt Grönblom
Honorary Vice-President

PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

Visit to Finland

The Land of Lakes and Forests . . .
The Land of the Bold and the Free

AFTER the Special Meeting in Sweden, a party of Members of the Institute paid a visit to Finland from 18th to 26th June, 1954, by personal invitation of Bergrådet Berndt Grönblom, Chairman and Managing Director of Oy Vuoksenniska A.B. The party consisted of 45 Members and ladies. It included the President and Mrs. Lyttelton, the Secretary, some Members of Council, and a few other Members from the United Kingdom, France, the Netherlands, and Sweden.

This short account gives the programme. Some notes by Sir Charles Goodeve on matters of technical interest follow. It is probable that another paper giving more detailed information on the development of the Finnish iron and steel industry will be published later.

The party arrived at Åbo (Turku) early on Saturday, 18th June, after a pleasant journey by ship from Stockholm. The morning was spent in Åbo, the oldest and second largest town in Finland and the seat of the first bishopric and university. The chief visit was to the blast-furnace of the Vuoksenniska Company. Other places seen included the Castle (built in the 13th and 14th centuries, and severely damaged in the Winter War of 1939–1940) and the Historical Museum, the Cathedral (founded in the 13th century), the Gallery of Modern Finnish Art, and the extremely interesting Crafts Museum—some dozen small wooden houses which alone escaped the devastating fire of 1827 and which have been fitted up as workshops, where various crafts (such as comb-making, pottery, carpentry, watchmaking, printing, bootmaking, weaving, embroidery, etc.) are carried on by skilled and mostly elderly craftsmen in the traditional manner. Later, Members and ladies had lunch with Mr. and Mrs. Grönblom at their country house of Kuva on the wooded peninsula of Runsala, a little to the north of Åbo.

STEN GRÖNBLOM, the son of Mr. Berndt Grönblom, was born in 1914. He received his technical education at the Institute of Technology of Finland, where he was awarded the degree of dipl. engineer (chemistry), and at the Royal Institute of Technology in Stockholm, where he studied mining science.

Mr. Grönblom participated in the Finnish war against Russia. In 1942 he joined Osakeyhtiö Vuoksenniska Aktiebolaget, a firm founded by his father, and held the appointments of Mining Engineer at Haveri Mine and Manager of Mätäsvaara Mine. He is a member of the Board of the Company, and since 1944 he has been Manager of the Imatra Iron and Steel Works. Mr. Grönblom became a Member of The Institute in 1947.

In the late afternoon, Mr. Grönblom's guests went on board a specially chartered steamer, the "*Per Brahe*." They were accompanied by Mr. and Mrs. Berndt Grönblom, Mr. and Mrs. Sten Grönblom, Mr. and Mrs. Fjalar Holmberg, Mr. and Mrs. Nils Hellén, Miss Nora Buch, and other Finnish friends. During the next three

days the ship cruised eastwards along the coast almost to the Russian frontier, putting in at a port each day and anchoring each night in some sheltered bay in the wonderful archipelago which joins sea to land. The sea was calm, the sun shone, and bathing was popular, even though to some the water seemed cold.

On the first day (20th June) there was a visit to Fiskars A.B., the second largest producer of steel in Finland. (Three generations of the von Julin family have been Members of the Institute.) The Company's scattered plants are mostly situated some miles inland from the little port of Ekenäs. Members and ladies had tea with Mr. and Mrs. Lauri Helenius at the Manor House of Fiskars. They will long remember also the visit to the 13th century church at Pojo, the organ and the moving singing of "*God Save the Queen*" in English by a small Finnish choirboy.

The next day was spent at Helsinki (Helsingfors), the capital of Finland. Various local industries were seen (these include a cable works, a glass factory, and the famous Arabia pottery), but most of the time was spent in sightseeing. There was a drive through the city and a visit to the Olympic Stadium. Visits were also paid to the chief buildings of historical or architectural interest. Helsingfors, the "White City of the North," is distinguished by its fine situation above the island-spangled sea and by the beauty of its buildings. Among these are the Great Church, the University Library and the classical Senate Square built by Engles in the first half of the 19th century, the imposing Parliament House by J. S. Siren, and the Station by Eliel Saarinen, who is probably the best known of modern Finnish architects. The inhabitants are proud of their city and do not grudge money in adding to its beauty; avenues and squares are decorated with statues by Vallgren, Felix Nylund, and the great Aaltonen. A short time was spent in a well-equipped hospital for backward children built with the help of contributions from Swedish trade unionists, and in the sadly impressive military cemetery, where Marshal Mannerheim rests on a bluff above the sea, surrounded by many thousands of his men who died in defending the freedom of their country.

The day in Helsinki came to an end with a grand dinner and dance at the Brändö Casino, to which many other guests were invited; and in the early hours of the morning the ship sailed again. There was no time to call at Borgå (Porvoo) or Kotka, but on the morning of the final day of the cruise (22nd June) the steamer put in at Sunila. Members went to the Sunila Sulphate Pulp Mill and the Karhula Steel Foundry, Engineering Shops, and Glass Works of A. Ahlström Oy. in the Kymmene valley.

The party left the "*Per Brahe*" at Hamina (Fredrikshamn) on the afternoon of Tuesday, 22nd June, and motored through Lappeenranta to Imatra, some 60 miles to the north-east and less than three miles from the Russian frontier. The only rain during the whole week was a heavy thunderstorm on this day. At Imatra the party was put up at the comfortable State Hotel. In the evening they met members of the staff of the steelworks, among whom are a number of Members of the Institute.

On the next day (23rd June) Mr. Holmberg gave a brilliant account of various special processes developed at the Imatra Steelworks of the Oy Vuoksenniska A.B., and later Members visited the works.

The party then drove to Savonlinna, 80 miles to the north. Part of the way was along the famous Punkaharju Ridge—a wall of granite several miles long but in places only a few yards wide, which divides two great lakes. There was one stop, at Punkaharju, for a bathe (the lake water was delightfully warm) and a meal, and another for tea at the great mediaeval castle of St. Olaf. After dinner in a hotel, the party cruised on the lake near Savonlinna and round St. Olaf's Castle in a small steamer to watch the fires which are lit on the shores to celebrate Midsummer's Eve. Midsummer's Day was spent in travelling down Lake Saimaa to Lappeenranta. Lake Saimaa is part of one of the three main lake systems of Finland; the area of this, the largest, is greater than that of the whole of the Netherlands. Wide stretches alternate with narrow straits; in places there are many rocky wooded islands; on the shores there are occasional villages and clearings, but the prevailing impression is one of beautiful expanses of water ringed by grey rock and black forest. At Karhusaari Island, near Lappeenranta, some Members and ladies went to the Sauna or Finnish bath—and said they enjoyed it. After dinner in the restaurant, the party were taken to the station on the mainland and then travelled in sleeping cars overnight to Helsingfors. The last day (Friday, 25th June) was spent in Helsingfors. In the evening, the British Minister and Mrs. Creswell gave a cocktail party at the Legation, and later there was a final dinner at Fiskartorpet restaurant. Members of the party spent the night at the Hotel Vaakuna and most left next day to travel home by air or sea.

One result of this journey has been that a small but representative party of Members of the Institute have met many people in Finland—industrialists, scientists, technicians, and others—and have got to know their hosts under conditions which will ensure that lasting friendships have been formed. They have learned something of the Finnish way of life. Another result has been that they have seen much of Finnish industry and something of her civilization—her cities, villages, private houses, and hotels; a little also of her immense lakes and forests and of the beautiful archipelagos that surround her shores. They have learned something of Finnish character and determination. The visit was short, but the opportunities for getting a representative picture of Finland were exceptionally favourable. The most durable memories will be of unstinted hospitality and considerate forethought, and the most lasting impression one of gratitude for the endless trouble taken by hosts and hostesses to add to the comfort and pleasure of their guests.

K. H-M.

THE IRON AND STEEL INDUSTRY OF FINLAND

By Sir Charles F. Goodeve, O.B.E., F.R.S.

This report is based on information received by the author as one of a party visiting Finland in June, 1954, as guests of Mr. Berndt Grönblom.

Introduction

THE iron and steel industry of Finland is small but has grown in a striking way since the war. Until 1944, iron production was on a very small scale and steel production about one-half what it is now. The increases since then are mainly due to the needs of war and to the peace treaty with Russia, in which it was stipulated that reparations were to include a large proportion of goods based on metals, principally steel. These reparations were paid off in 1952. Nevertheless, the current steel consumption is still about three times production, which is at the rate of 180,000 tons per annum.

The main part of the iron is made in a blast-furnace belonging to Oy Vuoksenniska A.B. at Åbo (Turku) in the south-west corner of Finland, and in an electric furnace of the Tysland Hole type at this company's iron and steelworks at Imatra, about two miles from the Russian frontier. A few thousand tons of pig iron are made from scrap in an open electric furnace at the plant of the Wärtsilä Engineering Company.

Two-thirds of the steel industry belong to the Vuoksenniska company, and the steel is produced at Imatra. The next largest producer is the Fiskars company, whose main business is the manufacture of a large range of metal products varying from penknives to steel furniture. A small amount of open-hearth steel is made at Dalsbruk by the Wärtsilä company, and there are three producers of electric-furnace steel for castings.

The trade and manufacture of Finland have varied so much in recent years that it is very difficult to describe them in a quantitative manner. The figures given in this report can therefore only be considered as approximate.

IRONMAKING

While Finland probably has very extensive deposits of good iron ore including magnetite, most of these are too remote and scattered to justify development as yet, especially in the face of the Swedish mining across the Gulf of Bothnia. There have for long been hopes of a change in this situation, but meanwhile the ironmaking industry depends on imported Swedish ore plus pyrites residues (purple ore). A state-owned mine has recently been opened at Otanmäki in the middle of Finland and now produces about 180,000 tons per annum of magnetite concentrates separated from ilmenite. As it contains 6% TiO_2 its use in any one blast-furnace is limited, and so it is mainly exported.

Finland has no coal, and all metallurgical coke must be imported. Supplies come from various sources, predominantly from Poland, Germany, and the U.K.

The ironworks at Åbo is conveniently situated near its own wharf, to which it is connected by a rope-bucket conveyor. The port will take ships up to 27 ft. draught and is kept ice-free by breakers all winter. Some ore (but not coke) must be stored for the winter season because of the closure of Swedish despatching ports and the problems of handling frozen ore. There is no crushing plant and the imports are mostly of fines.

The blast-furnace is of ordinary design with a McKee top and carbon-lined hearth and bosh. It has a hearth diameter of 3·7 m. (12 ft. 2 in.) and is operated mostly on 100% sinter, producing 80,000 tons per annum. The product is mainly foundry iron but some hematite and basic is produced. The coke rates for these products are, respectively, 19·5 (3% Si), 19·0 (3% Si), and 14·2 (1·3% Si) in cwt. per ton of iron, but there is the usual rise with poor-quality coke. The furnace productivity, 1500–1600 tons per week, is good for this size of furnace and is due to a combination of a moderately low coke rate and a high driving rate[1] (about 17 tons of coke per sq. ft. of effective area per week).

The blast-furnace is well fitted with modern control devices. It has a gas analysing beam of the type used at Domnarfvet for some years.[2] This is situated some

Sir Charles Goodeve is Director of the British Iron and Steel Research Association.

distance below the stockline and makes gas analyses possible at eight points from the wall to the centre.

Lining wear is followed by the use of radioactive cobalt-60 pellets and a scintillation counter as a detector. This method was first devised in B.I.S.R.A.,[3] but has been extensively developed in this works. There are seventeen measuring points: three are fitted 120° apart at each of four levels in the stack, four more are over alternate tuyeres, and one is over the iron notch. At each measuring point in the stack there are five pellets in a line 4, 8, 12, 16, and 20 in., respectively, from the outer plate. In the bosh there are four pellets up to 16 in. The activities of the sources had been suitably graded (by cutting from a 1-mm. dia. wire) so that the radiation intensity at the outer wall was directly proportional to the number of pellets left. The intensity of the innermost pellets is 5 mc. The equipment had only been in for a few months but had already proved to be useful.

The sinter plant is of the Swedish A.I.B. type, with twelve rectangular movable pans of area 7 sq. m. (75 sq. ft.). A particularly effective loading machine lays a bottom bed of returned screened sinter, a main bed of mixture, and a top igniting layer of coke breeze, in 30 sec. One of the striking features of the plant is its freedom from dust, achieved largely through special arrangements at the discharging point. As the capacity of the plant is in excess of present requirements, the suction is kept on for an extended period to remove as much sulphur as possible and to cool and oxidize the sinter. With a cycle time of 40–65 min. and a crew of six, a production of 240 tons per 8-hr. shift has been attained with an average of 2400 tons/week in 12 shifts. The sinter is transported to the blast-furnace bins at a temperature of up to 500° C., but becomes cooled to normal temperatures before it is charged to the bins.

Limestone comes partly from domestic sources and one-eighth of the total requirements are added to the sinter mixture. The blast-furnace slag is sold for grinding and mixing in cement.

An important part of the economy of the plant is the conversion of the surplus blast-furnace gas to electricity, partly for export. The power plant is equipped with a Velox boiler with the usual exhaust gas-turbine driven compressors, pressure-charged combustion, and forced circulation.

In keeping with the above-described points of advanced technology, the whole plant gives the appearance of being very efficient. One would deduce, therefore, that the cost of producing iron at Åbo will depend mainly on the world prices of sea-borne ore and coke, and that this plant should be able to hold its own against normal competition from abroad.

The other major iron-producing unit is an electric smelter of 20,000 tons capacity at Imatra. This is based on pyrites from ore mined in central Finland and burned at various pulp mills to provide sulphite. The electricity, which is supplied by the local state-owned hydro-electric station, is at a favourable price, in accordance with a contract made before the war and due to continue until 1960. In view of the great demand for electricity in Finland, which cannot readily be satisfied by developing other hydro-electric sources, it is rather likely that, when the present contract expires, the price of electricity at Imatra will rise very substantially and make this electric smelter uneconomic.

The pyrites residues are agglomerated by a pelletizing process with some important and unique features. This process has been developed by the steelworks staff, patented, and the rights sold to the Lurgi company. In the process most of the copper and zinc and much of the cobalt and gold in the pyrites residues are removed during the process of roasting the pellets. The plant has been operating for some years, producing 20,000 tons of pellets per annum. At the time of the visit it was closed down for modifications and expansion and soon would be producing 60,000 tons per annum.

The following is a brief description of the process. The pyrites residues, containing about 0·7–2·5% Zn, 0·4–0·9% Cu, and about 0·5% Co, are mixed with a strong solution of calcium chloride. This is fed on to a pelletizing disc of a new type developed in Switzerland from a Czech invention. The disc is about 5 m. dia. and rotates about an axis inclined at an angle of 45°. A rim around the circumference contains the pellets until they have grown to the required size. The inventors claim that this pelletizing device produces a very even size-grading of pellets at about 20 mm. dia. The pellets are fed to a shaft kiln fired by oil and raised to about 1200° C. The kiln is kept under highly oxidizing conditions and the highest temperature zone is kept near the top. Under these conditions the copper, zinc, and most of the cobalt and gold are distilled off from the pellets as chlorides.

The gases pass through a settling chamber followed by an electrical precipitator. In these the metallic salts are recovered and sold as sulphates; it is necessary to have a certain amount of sulphur in the residues to provide the SO_3 to carry out the latter conversion. The gases finally go through a lime washing tower to recover the hydrochloric acid gas as calcium chloride.

This process obviously has a number of attractive features and it seems likely that much more will be heard of it in the future.

STEELMAKING AND ROLLING

About three-quarters of the steel produced in Finland is made in the electric furnaces (two of 25 tons and one of 12 tons, Héroult) at Imatra where there is installed a total capacity of 120,000 tons per annum in a well laid-out and spacious shop. The production is mostly bottom-poured killed steels for rails, sections, and wire rods, but a certain amount of alloy steel (including stainless) is also made.

The mill is also well laid-out and of a capacity considerably greater than that of the melting shop; indeed, on occasions it rolls billets obtained from Russia or other European sources. In addition to the blooming mill, there is a heavy rolling mill, a medium rolling mill, and a light section and continuous wire-rod mill. The plant also contains a wide variety of equipment for making other steel products such as tyres and welded pipes.

A novel variation of an old process for increasing

the yield from ingots was seen in use in the casting bay. This has been developed[4] through extensive trials in recent years and is now used for all types of steel. The process uses a thermite mixture of carefully chosen grading and composition, but differs from the normal methods using this material in that the bags of thermite are added only at a time when the last of the liquid in the ingot would be known just to have solidified. In others words, the pipe is allowed to form first and then the steel in the hot top is remelted by the thermite mixture and made to flow down and fill in the pipe. It then resolidifies under a vertical temperature gradient. Very high yields are obtained, and certainly the exhibited sections of ingots indicated that a satisfactory filling of the pipe is obtained. The demonstration showed the extreme simplicity of the method from an operating point of view. It is, of course, based on careful measurements of the times of solidification, and there is a great deal of 'know-how' in getting the right composition of the thermite mixture.

A 10% saving in the tap-to-tap time when making killed steel was achieved by removing the last of the sulphur by means of lime in the ladle. For example, a 29,000-kg. charge of steel to meet a 0·035% S specification is tapped at 0·05% S and the drop is produced by a dry mixture of 200 kg. of CaO, 70 kg. of CaF_2, and 20 kg. of FeSi previously added to the ladle. Precautions had to be taken to prevent any furnace slag coming over with the steel, at least until the end of the tap.

The open-hearth furnace owned by the Fiskars company is situated at Åminnefors. It produces ordinary steel for a medium section mill, a small bar mill, and a wire rod mill in a works nearby. The 40-ton all-basic furnace with its shop was built in 1946. It has single uptakes and is fired with single oil burners. The ingots (900 lb. each) are bottom-poured into big-end-up moulds. Eighteen of these ingots are cast from one runner and the moulds are arranged in the form of a six-pointed star. Three to four stars are cast from one heat. Annual production is about 20,000 tons.

It was of interest to see a new melting shop with only one furnace in it and manned partly by women. Plans are in hand for building a second furnace in this shop. Here, as at Imatra, the rolling-mill capacity is considerably in excess of the melting capacity.

OTHER TECHNICAL DEVELOPMENTS IN FINLAND

Numerous technical innovations were to be seen in Finland, especially at Imatra. It almost seems that the many problems threatening the economic and political security of the country have generated a strong attitude in favour of technical progress. The staff of the steelworks, in addition to their own experiences, have a very wide knowledge of the latest forms of steel technology throughout the world, obtained either through travel or by reading. At Imatra the laboratory for control of the chemical analysis of steel is well designed around an A.R.L. quantometer, and one is unlikely to find its superior anywhere. The gas producers are fitted with a device to saturate the primary air using some of the waste heat of the gas.

As an example of the wide fields in which technical advances had been made the development at Imatra of a simple form of gas washer might be quoted.[5] In this the gas is passed through a Venturi throat, at the narrowest point of which water is injected at the same speed as that of the gas (25 m./sec.). As the throat opens, the gas velocity falls and the water drops, retaining their velocity, pass on through and thereby clean out the dust particles. The action is mainly by impact, but there may be some effect due to condensation in the adiabatic expansion. The water jet also gives a strong pumping action which more than overcomes the pressure drop in the throat, giving a net gain of pressure of up to 60 mm. W.G. This is to be compared with a pressure *loss* of up to 300 mm. W.G. in a well-known Venturi type of gas washer used in America.[6]

Correspondingly, the total power consumption of the Imatra washer is low (0·6 kWh. per 1000 cu.m.), whereas for the same cleaning action and outgoing pressure the American cleaner requires about five times this power. The Imatra washer produces a uniform curtain of water droplets and loss of cleaning action through collisions between droplets is minimized.

The Oy Vuoksenniska A.B. had solved their problem of the recovery of zinc from zinc dross, formed in the galvanizing bath, through a process based on the varying solubility of zinc in lead with temperature.[7] This equipment consists of two iron tanks containing liquid lead held at 700° and 450° C., respectively. The dross is charged into the hotter tank and the lead dissolves out most of the zinc (solubility 10% at 700° C.). The lead then circulates by assisted convection (through a heat exchanger) to the cooler tank, whereupon the zinc separates as liquid drops (solubility 2% at 450° C.) and floats to the surface, where it is skimmed off and cast. The residues from the dross, containing 2–3% Zn, are rejected. The whole process gives 92% recovery, and with one man in three shifts per week yields 800 tons of zinc per annum. The recovered zinc contains 0·03% Fe and 1·2% Pb.

CONCLUSIONS

In general it seems that there is still much to be done in the Finnish steel industry to raise productivity and to overcome the disadvantages of meagre natural resources and of small internal markets. Nevertheless, it was a salutary experience to the visitors to see such important technical progress taking place on the geographical fringe of the European steel industry.

The industries of Finland are of special interest to us in the U.K. because we are Finland's best customers. This is not only true in regard to the extent of trade, for Finland has a favourable balance of trade with the U.K., *i.e.*, we take more of her exports than we send back as imports. Russia is in a similar relationship, largely due to the fact that the flow of goods, originally started through reparations, continues because of its momentum, but now on a normal commercial basis. Finland also has a surplus of exports with the U.S.A., attained by a rigid control of imports

from that country. However, these three favourable balances are barely sufficient to meet the negative balances with other countries such as Holland, Sweden, and Germany.

Finland undoubtedly has many economic and industrial problems. None of these, however, seems to be as great as those through which she has already lived. In the last 10 years she has paid off part of an old debt to the U.S.A. and an enormous bill of reparations to Russia. She has rehabilitated 12% of her population which was displaced, mostly from territory ceded to Russia, repaired most of her war damage, built extensive hospitals and other public works, factories, etc., and raised the standard of living of her working people. All this has been achieved without a strong government in power. It is true that she has had in her favour high prices for her products based on wood, her 'green gold.' She has not had (or even been allowed) to spend any appreciable amount on defence, a fact which is to be compared with the U.K., where we have had to spend one-eighth of our national product. These favourable facts, however, do not detract from the extent of Finland's achievement.

Among the many problems is that of finding an export market for her expanded engineering industry, built up originally to provide the equipment for reparations. At the present time she is very much dependent upon Russia to take such exports. One of the first problems to be solved before she can extend her markets to the rest of Europe or abroad will be to get rid of her present dual exchange rate; the official exchange rate puts a high price on her exported goods, which is out of proportion to her real internal costs. There is, however, still a pent-up internal market which should keep up the demand for steel for some time. Her railway industry in particular needs modernization.

The British steel industry has for long exported finished steel to Finland. In plates and in some other products this trade is well based and is likely to survive a recession but, in view of the large excess of finishing capacity over steel melting, a recession would be likely to lead to a shift in imports from finished to semi-finished products. Indeed, imports of billets from Russia are already substantial. Finland is, however, effectively an island and most of her population live close to the sea. This fact is perhaps of more significance to the U.K. from a trade point of view than is her geographical proximity to Russia.

The main conclusion shared by all of the visitors to Finland was that a further extension of the present co-operation between the respective iron and steel industries would be well worth while to both countries.

Acknowledgments

The author is indebted to the many people who helped to asemble this information, and in particular to Mr. B. Grönblom, Mr. S. Grönblom, Mr. F. Holmberg, and Mr. I. Kjellman.

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2. W. Loorz, W. Feldmann, and M. Paschke: *Stahl u. Eisen*, 1943, vol. 63, pp. 2–14.
3. E. W. Voice: *J. Iron Steel Inst.*, 1951, vol. 167, pp. 157–161.
4. British Patent No. 716,419.
5. Swedish Patent No. 141,229.
6. W. P. Jones: *Ind. Eng. Chem.*, 1949, vol. 41, p. 2424; *see also* R. F. Jennings: *J. Iron Steel Inst.*, 1950, vol. 164, p. 318.
7. British Patent No. 696,466.

Correspondence on the Paper—

THE LENGTH OF OIL AND GAS FLAMES*

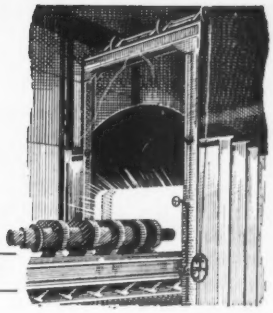
By A. L. Cude

Dr.-Ing. **H. Garbeck** (Hüttenwerk Rheinhausen A.G., Rheinhausen, Germany) wrote: Since the length of flames is very important in the heating of the soaking pits of a rolling mill, I should like to question the use of feet as the units of the abscissa in Fig. 1 of the paper. I should have expected the variable of the abscissa to be r_t or $(1 - r_t)$ instead of the expression given, all the more since $\sqrt{(qs'/u)}$ remained constant in the experimental work.

AUTHOR'S REPLY

Mr. **A. L. Cude** (I.C.I. Ltd.) wrote in reply: The term $\sqrt{(qs'/u)}$ is not constant, since s' refers to the density of the jet fluid, which in this case was a mixture of town gas and air of variable composition. The ratio q/u is constant because it is a measure of the burner size, and for these particular experiments only one burner was used. However, I preferred to retain the general form of the equation in order to avoid the confusion which results from the introduction of numerous special relationships, each applicable to only one particular system.

* *J. Iron Steel Inst.*, 1954, vol. 176, pp. 270–273.



An Investigation of Reheating Furnace Design and Performance

By F. A. Gray, F.Inst.F., A.I.M., and S. H. Brooks, B.Eng., A.M.Inst.F.

SYNOPSIS

Long- and short-period tests were carried out on a continuous reheating furnace as part of a project designed to provide basic data which would assist in putting furnace design on a more fundamental basis, and also to be applied to the immediate improvement of the furnace tested.

The many variables affecting furnace performance were measured and their interrelationships studied. Apart from the well-known effect of output on furnace efficiency, it is shown that billets of 3 in. thickness and greater require more fuel and are associated with higher flue-gas losses than thinner ones at a given rate of output. The importance of furnace pressure has been amply confirmed, and quantitative data are presented showing its effect on air infiltration, blowout, and fuel consumption. The progress of combustion through the furnace was studied in relation to gas flow, furnace pressure, and air/gas ratio.

A technique for continuously measuring the upper and lower surface temperatures of billets passing through the furnace was developed and enabled temperature distribution in the stock and heat-transfer rates to be measured. The factors affecting temperature equalization in the stock and the general temperature and heat-transfer distribution throughout the furnace are presented and discussed. It is suggested that two-zone heating is desirable for all billets of 3 in. thickness and greater for good temperature equalization in the stock. The overall and sectional heat-transfer coefficients have been calculated and the continuity of furnace operation was found to be the most important variable affecting the overall heat-transfer coefficients and the furnace efficiency.

The results have also been applied to the redesign of the furnace tested, as outlined in the paper. It is estimated that the modifications should enable the maximum output to be increased by about 20% and give approximately 20% saving in fuel.

889

Introduction

CONSIDERABLE progress has been made in recent years in the design and operation of reheating furnaces, notably as a result of investigations carried out by such workers as Sarjant in the U.K., Trinks, Hottel, and Eberhardt in the U.S.A., and Schack and Heiligenstaedt in Germany. Present knowledge is, however, still insufficient for design and operation to be on a fully scientific basis. This applies particularly to the mechanism of heat transfer, temperature distribution, and flow of gases.

The United Steel Companies Research and Development Department decided to undertake, in conjunction with the Companies' branches, a series of investigations by carrying out trials on furnaces of different types with two objects:

(i) The collection and correlation of data on the factors involved for the purpose of ultimately putting furnace design on a more fundamental basis

(ii) The immediate improvement of the design and operation of existing furnaces by applying the results of the investigation to the furnace tested and to furnaces of similar types.

The present paper describes the first of these investigations, which was made on a continuous reheating furnace in collaboration with the Fuel Department of Steel, Peech and Tozer.

Three types of trial were carried out:

(*a*) Long period
(*b*) Short period
(*c*) Supplementary.

Long-Period Trials

In these trials, performance was studied by examining data collected over a comparatively long period under normal working conditions. Statistical analysis was then used to study the relationships between the variables. These data were obtained by fitting recording instruments to the furnace and taking readings of

Gas flow, temperature, and pressure
Air flow, temperature, and pressure

Manuscript received 22nd December, 1953.

Mr. Gray and Mr. Brooks are in the Research and Development Department of the United Steel Companies, Ltd.

Furnace pressure
Inlet and outlet flue-gas and air temperatures at recuperator
Weight and size of material heated (per hr. in any period)
General times of heating, mill stoppages, etc.

The times of rolling any one finished size, together with the estimated weight of billets charged and the weighed amount of finished products, enabled each shift to be subdivided into periods during which only one finished size was produced. The gross rolling times included the time taken to change rolls and all stoppages (including meals and breakdowns). The object of these trials was, firstly, to indicate the more important variables, so that they could be studied in more detail during short-period or supplementary trials, and, secondly, to cover a larger range of conditions than would otherwise be possible.

The control of the furnace was in the hands of the furnace operator. Some instruction had, however, been given previously in damper control.

Short-Period Trials

The short-period trials, which were of 8 hr. duration, had an advantage over the long-period technique in that personnel and equipment could be concentrated on the furnace and measurements taken that would have been impossible to record over long periods. Their purpose was therefore to measure a large number of variables simultaneously, thus making it possible to construct heat balances and make a detailed study of the relationships between the operating factors at different rates of loading and billet sizes. The factors studied and the measurements taken are shown in Fig. 1.

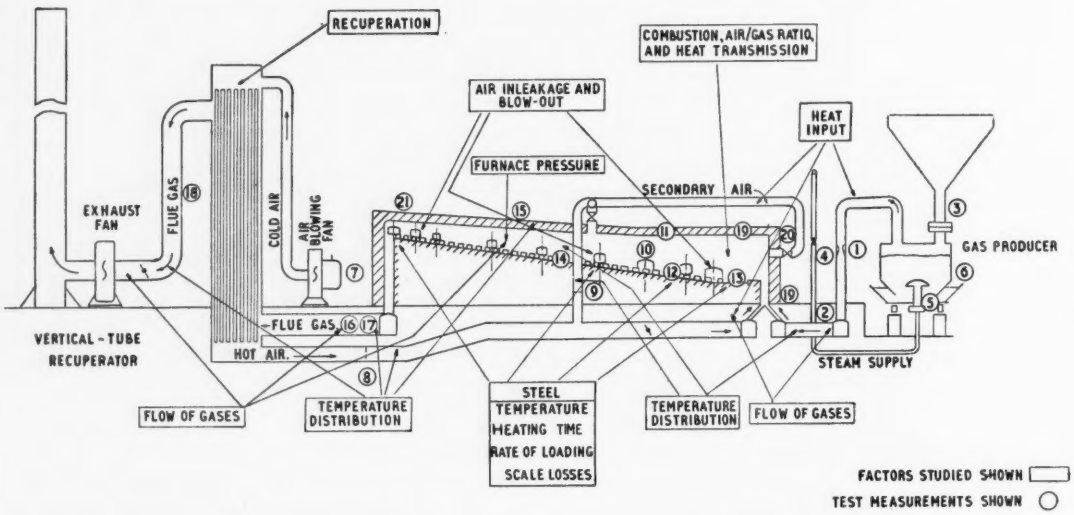
Seven short-period tests were made. These were arranged to cover a range of billet sizes from 2 in. to 4 in. square, and output rates of 20–40 tons/hr., so as to include the effect of loading on performance.

The control of the furnace was, in general, left in the hands of the operators, except where obvious deficiencies of air existed or where changes were required to enable special tests to be carried out. One important variable, however, namely furnace pressure, was not in the hands of the furnacemen. This was maintained at a pre-set value during each trial by means of an automatic controller operating the stack damper. This instrument was installed especially for the trials because earlier experience had suggested that the variability of performance due to this factor alone would render short-term-trial results difficult to interpret. The good thermal efficiencies obtained are also thought to be due partly to this equipment.

Averages over the full test periods were determined for the measured variables and these are given in the Appendix, together with the heat quantities and volumes calculated from them.

Supplementary Trials

These were made either to develop measurement techniques or to study a particular variable when it



1. Gas flow, temperature, and pressure at producers and furnace
2. Producer-gas analysis, including tar and moisture
3. Coal consumption and analysis
4. Steam pressure to jet blowers
5. Temperature of steam and air blast
6. Condition of firebed and cleaning times

Producer gas

7. Total air flow, temperature, pressure, and humidity before recuperator
8. Total air flow, temperature, and pressure after recuperator and at furnace
9. Secondary air flow

Combustion air

10. Temperature and analysis of combustion gases
11. Roof temperature and furnace pressure
12. Steel surface temperature (optical pyrometer)
13. Steel surface temperature (radiation pyrometer)
14. Steel top and bottom surface temperatures (attached thermocouples)

Furnace chamber

15. Temperature of outside surface of brickwork
16. Total flue-gas flow through recuperator
17. Temperature, pressure, and analysis of flue gases entering recuperator
18. Temperature, pressure, and analysis of flue gases leaving recuperator

Flue gases

19. Inlet and outlet temperatures of cooling water
20. Cooling water flow

Cooling water

21. Quantity of steel charged

Steel

Fig. 1—Factors studied and test measurements

was inconvenient to do this during the short-period trials, *e.g.*, the development of billet-temperature measurement and the study of furnace-pressure distribution.

DESCRIPTION OF FURNACE INVESTIGATED

The investigations were made on a continuous pusher-type furnace (*see* Fig. 2) serving a Morgan semi-continuous bar mill. The stock consists of billets $1\frac{3}{4}$–4 in. square and slabs 2 in. thick and 4–$6\frac{1}{2}$ in. wide. The maximum output of the furnace is 40 tons/hr.

The furnace is fired with hot raw producer gas supplied from two 10-ft. internal dia. Morgan gas machines located about 50 ft. from the furnace. The combustion air is fan-blown and is preheated in a Schack metallic recuperator (heating surface 3000 sq. ft.) before passing to the primary and secondary air ports at the furnace.

The hearth is 44 ft. 6 in. long × 32 ft. wide between walls, and the centre-lines of the charging and discharging doors are 40 ft. apart. The corresponding hearth areas are 1425 sq. ft. and 1280 sq. ft. The hearth is non-ventilated and has a slope of 1 in 7 up to a point 3 ft. 10 in. from the burner bridge wall.

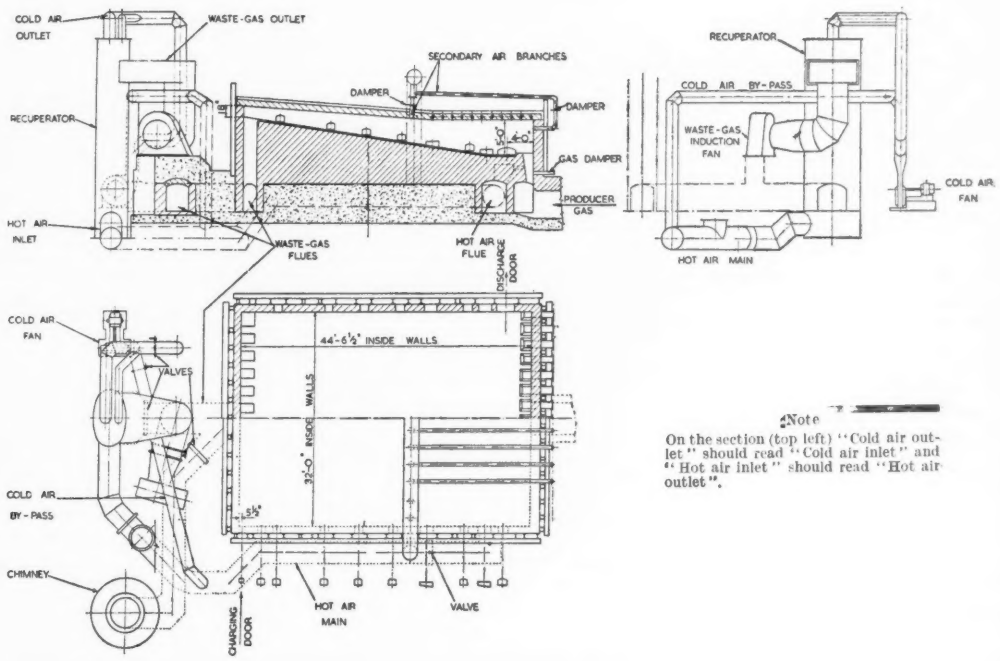
The walls are $13\frac{1}{2}$ in. thick and are composed of semi-silica in the hottest parts of the furnace and firebrick in the remaining portions. The roof is suspended; for the first 16 ft. 6 in., the bricks are supported on 11 water-cooling pipes running across the width of the furnace, and for the remaining 28 ft. the bricks are carried directly on metal hangers.

There are 15 gas and air ports adjacent to the end wall, equally spaced across the furnace; an isometric view is shown in Fig. 3. The flame is projected upwards towards the roof parallel to the end wall. Secondary air ports are placed in two positions: in the front-end wall above the gas ports and in the roof 18 ft. from the gas ports.

There are 12 waste-gas ports and downtakes situated immediately in front of the end wall at the charging end of the furnace. The downtakes deliver into a collecting flue with a **T**-branch leading into the metallic recuperator. The draught for overcoming the resistance of the flue-gas system is provided by an exhaust fan and is regulated by a butterfly valve placed between the fan and the recuperator. During the short-period trials, this was automatically operated by a furnace-pressure controller.

The furnace is side-charged and the billets are moved down the hearth by steam-driven pusher arms which pass through the back end wall. The furnace is side-discharged by a steel ram moved by electrically driven pinch rolls.

Most of the measurements in the furnace chamber were taken through the roof, and for this purpose a series of holes were drilled through the brickwork to a prescribed pattern, as shown in Fig. 4. The rows down the furnace length and the columns across the



Note

On the section (top left) "Cold air outlet" should read "Cold air inlet" and "Hot air inlet" should read "Hot air outlet".

Fig. 2—General arrangement of furnace

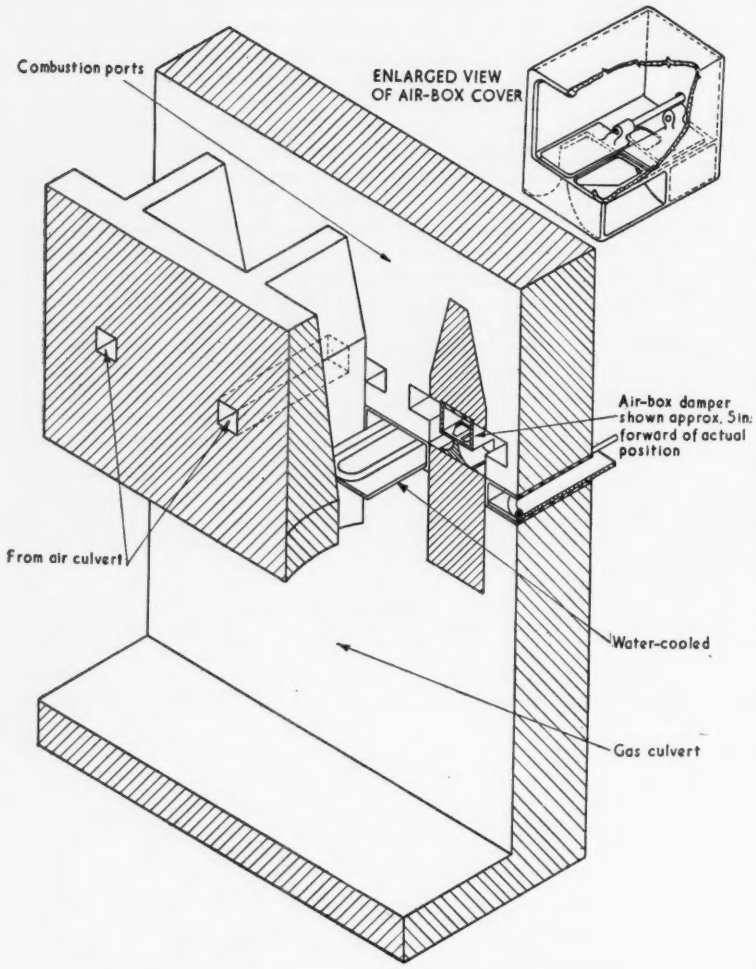


Fig. 3—Isometric view of combustion ports

furnace width were designated *A* to *D* and 1 to 5, respectively, for reference purposes. This arrangement enabled the temperature, flow, pressure, and combustion conditions to be explored in the vertical and horizontal axes within the furnace chamber.

INSTRUMENTATION

During the short-period trials 45 instruments were used to measure 80 variables. Recording instruments were used, as far as possible, to reduce the number of observers to a minimum. Recording instruments only were used during the long-period trials when data were collected over several weeks. In this case, 14 instruments were used to record 17 variables.

The application of these instruments in some cases presented considerable difficulties, either in providing an apparatus which would stand up to the temperature conditions, or, alternatively, in finding a method which would give the desired information. Where special techniques had to be developed, supplementary investigations and calibrations were carried out. Examples of such difficult measurements are those of combustion-gas temperature and heat transmission in the furnace chamber.

Flow Measurement

Producer Gas—The hot raw producer gas was measured by Venturi throats in the downcomers from each producer. These were made of refractory concrete using wooden formers.

To keep the Venturi throats and pressure pipes clean, four compressed-air jets were installed for scouring the Venturi throat, and tees and plugs were provided, together with air connections, for facilitating the rodding and blowing of the pressure pipes. The Venturi throat was scoured by compressed air and the pressure pipes were rodded and blown out every 4 hr. The flow meters were isolated for the few minutes occupied in carrying out these operations.

These provisions proved to be entirely successful, and no trouble at all was experienced with dust or tar deposits. Examination of the Venturi throats after 6 months operation showed them to be free from deposits and their dimensions to be unchanged.

Air—Three air-flow measurements were taken, orifice plates being used in each case. These were:

(i) Air volume delivered to the recuperator by the air-blowing fan
(ii) Total preheated air to the furnace
(iii) Preheated secondary air.

The orifice plate for measuring the total preheated air to the furnace was used in a non-standard location and the discharge coefficient was obtained by calibration with a scale model.

Waste Gas—Site conditions did not permit the use of an orifice plate for metering waste-gas flow to the recuperator. The measurement was therefore made by recording the pressure drop across the waste-gas side of the metal recuperator on a ring balance meter. Calibration was carried out by Pitot-tube traverses across the waste-gas flue immediately before the recuperator, and also by the calculated volume of flue gases from their analysis and the measured volume

of producer gas burned. When the second method of calibration was being carried out, the furnace was put under suction to avoid loss of combustion products by ' blow-out.' Good agreement was obtained between the two methods.

Cooling Water—The flow was measured by recording the supply pressure to the various water-cooled parts of the furnace. This was converted into terms of flow by a tank calibration.

Gas Analysis

Producer Gas—The normal methods of gas analysis were used for determining the composition of the producer gas and a special method was used for ascertaining the tar and moisture contents, based on the method developed by the British Coal Utilization Research Association,[2] which consisted of aspirating a measured volume of gas from the main gas stream through tared absorption tubes. The latter were immersed in solid CO_2, which condensed the tar and moisture contained in the sample. The total tar and moisture contents were obtained from the increase in weight of the tared train. Moisture was determined on the condensate by the Dean and Stark distillation method and the tar content was calculated by difference.

Furnace Gases—The combustion gases in the furnace chamber and the flue gases before and after the recuperator were analysed on site, using Orsat apparatus. In the former case, water-cooled sampling probes were used. These were inserted through the furnace roof at points *B*3 and *D*3 (*see* Fig. 4). Gas samples were drawn at three levels (1 ft., 2 ft., and 3 ft., respectively, from the inside of the roof) with the probe at *B*3, and at two levels (3 in. and 1 ft. 3 in. from the inside of the roof) with the probe at *D*3.

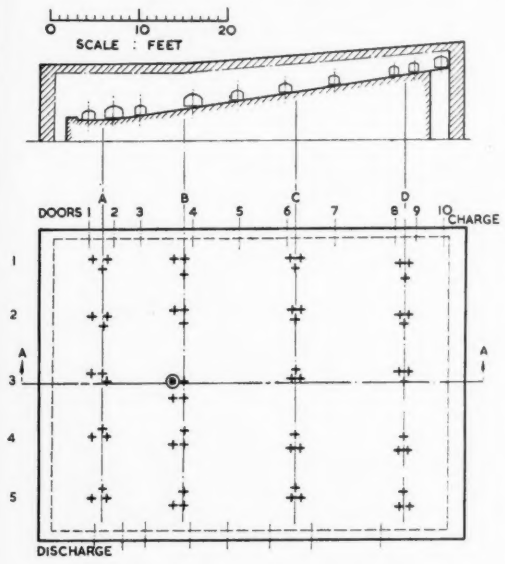


Fig. 4—Diagram of measuring points in furnace roof

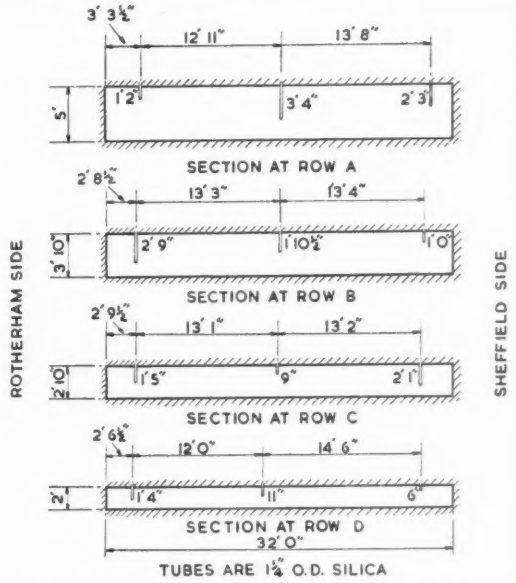


Fig. 5—Position of thermocouples for measuring combustion-gas temperatures

The gases were drawn continuously and at high speed from the probe to the gas-sampling apparatus (located at floor level) by means of a compressed-air ejector.

The samples of flue gas from the waste-gas flues before and after the recuperator were taken through silica tubes and drawn directly into the Orsat apparatus.

Pressure Measurement

Conventional apparatus was used for measuring the pressure of the producer gas, air, and waste gas. Furnace-pressure surveys were taken with a micromanometer reading to 0·0002 in. W.G. For reasons previously mentioned, the furnace pressure was automatically controlled during the short-period trials. A record of the furnace pressure at the control point was also taken.

Temperature Measurement

Internal Roof Surface—The temperature of the underside of the roof was measured at 12 points, using Pt/Rh and chromel/alumel couples, according to the temperature level. The couples were protected by sillimanite sheaths, the ends of which were flush with the underside of the roof. Change in calibration of the chromel/alumel couples was found to be insignificant, but there were considerable changes in the Pt/Rh couples, necessitating the application of corrections.

Gases in Furnace Chamber—The measurement of the temperature of the gases at 12 points in the furnace chamber presented some difficulty. It was not considered to be practical to operate 12 suction pyrometers simultaneously and continuously for an 8-hr. period. The procedure adopted was therefore to use rare-metal sheathed couples previously calibrated *in situ* with a suction pyrometer measuring the

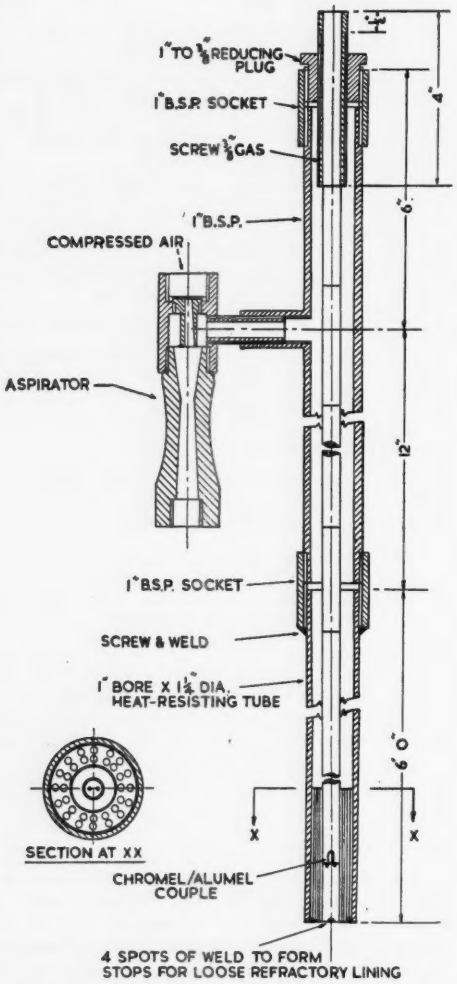


Fig. 6—Details of uncooled suction pyrometer

temperature at the same point. The gas temperatures were measured at three different positions in each of the four rows across the furnace, at the depths shown in Fig. 5.

To avoid the disadvantages of a water-cooled suction pyrometer, an uncooled instrument was designed (Fig. 6). The compressed-air ejector fitted directly on to the pyrometer tube, avoiding the difficulty of handling hot gas between the pyrometer head and the normally remote ejector. A small compressed-air-supply pipe was connected to the ejector, and the hot gas passing up the pyrometer tube was discharged to atmosphere with the compressed air. The air passing through the ejector also assisted in cooling the pyrometer head.

The pyrometer tube was detachable from the head, to enable tubes of different materials to be used for the lower portion, according to the temperatures to be measured. Mild steel was used up to 800° C., and heat-resisting alloy (70% Ni, 30% Cr) above 800° C. Silica sheaths were first used to measure temperatures above 1200° C., but they spalled badly on cooling. The heat-resisting steel tubes were then found to be satisfactory up to 1350° C. for short periods, as they were suspended vertically.

A Schack-type multihole radiation shield 4 in. long was used at the end of the tube, and this was prevented from falling out by four small spots of weld metal. In the case of the refractory tubes, the bottom of a closed-end tube was cut off, leaving just enough of the curved end to prevent the shield from falling out. The thermocouple junction was located half-way up the Schack shield. Bare chromel/alumel 22 S.W.G. wires were used for temperatures up to 1000° C. and 16 S.W.G. wires for temperatures up to 1350° C. The chromel/alumel wires had a limited life, but they were easily replaceable, and it was found that these wires continue to give accurate readings until they actually break.

Producer Gas, Flue Gas, and Preheated Air—Sheathed base-metal thermocouples were used for these measurements. A search couple and a suction pyrometer were used to traverse the flue-gas and preheated-air ducts to check that the installed couples gave a temperature representative of the gases passing.

Steel Temperature Measurement

Four methods were used to measure steel temperature:

(i) Optical pyrometer sighted through an air-swept tube

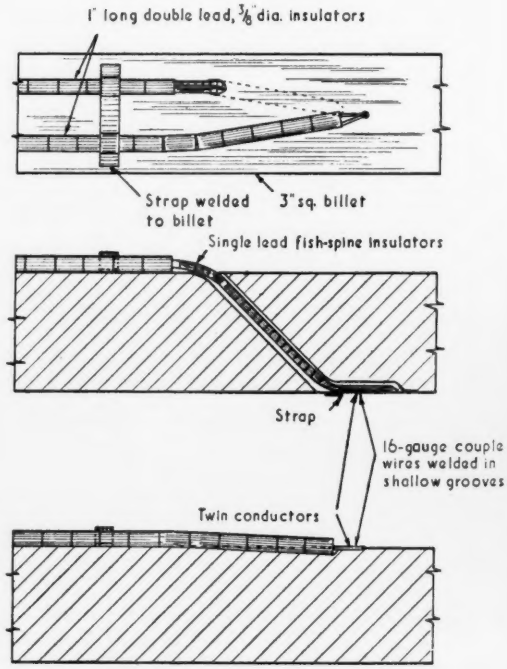
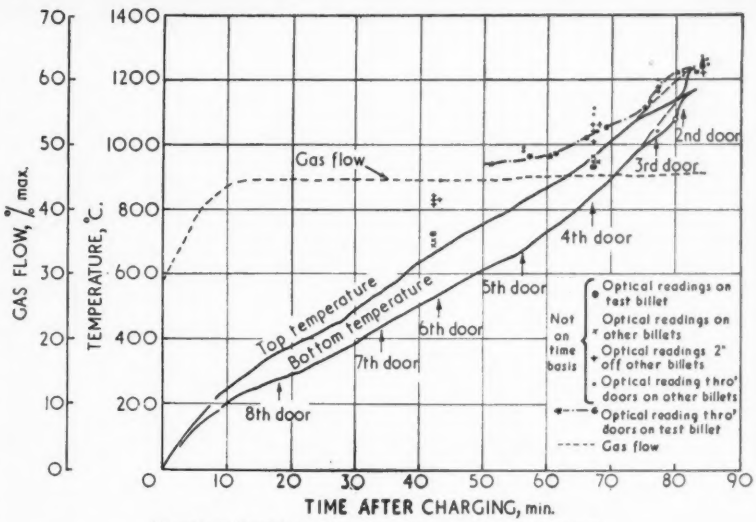

1" long double lead, ⅜" dia. insulators
Strap welded to billet
3" sq. billet
Single lead fish-spine insulators
Strap
16-gauge couple wires welded in shallow grooves
Twin conductors

Fig. 7—Diagram of billet thermocouples

(ii) Radiation pyrometer sighting through furnace side wall
(iii) Continuous measurement of temperature of top and bottom surfaces of billets travelling through the furnace by means of welded-on thermocouples
(iv) Optical-pyrometer readings after the second stand in the mill.

Optical Pyrometer through Sighting Tube — An optical pyrometer sighted through an air-swept tube was used to measure the billet surface temperatures at as many points as possible in the furnace during the short-period trials. To do this, 1½-in. bore tubes were lowered through the furnace roof on to the surface of the billets, the tubes being swept continuously with compressed air to prevent ingress of flame and smoke. The surface temperatures of the steel were measured with a disappearing-filament optical pyrometer after the tubes had reached approximately the same temperature as the steel. The method was found to give good accuracy over a large portion of the furnace. During the short-period trials, steel surface-temperature readings were taken by this method at regular and frequent intervals at three points across the furnace at both *A* and *B* rows.



All readings through sighting tube, except where otherwise stated.

Fig. 9—Preliminary trials of methods of steel-temperature measurement

Radiation Pyrometer through Furnace Wall—During the last two short-period trials, a total-radiation pyrometer was sighted through the furnace wall on to the top surface of the billet, at a position approximately midway on the billet length and opposite the discharge door. This was to determine its suitability as an automatic control instrument. The temperature was continuously recorded by a potentiometric recorder.

Continuous Measurement of Top and Bottom Surface Temperatures of Billets Travelling through Furnace—It was desired to ascertain the uniformity of heating of the steel (*i.e.*, the difference between the top and bottom temperatures of the steel billets during and at the completion of the heating) and also to measure the rate of heat transmission along the furnace length. Both these objects would be accomplished if the top and bottom temperatures of the billets could be continuously measured as the billets travelled through the furnace. Not only would the degree of temperature uniformity be shown, but the billet would also act as a heat-flow meter. After a number of experiments, the difficulties were finally overcome and a successful technique was evolved.

The billets on which the temperature measurements were made were prepared beforehand and then charged into the cold end of the furnace in the normal way. The temperatures were measured by thermocouples welded into the top and bottom surfaces of the billet. The construction finally adopted is shown in Fig. 7.

In preparing the test billets, the free lengths of thermocouple wire were tied to the billet with string to prevent them being damaged during the charging operation. This is illustrated in Fig. 8, which shows a test billet ready for charging. After charging, the string burned away and released the loose thermocouple wires, so that the free ends could be drawn through one of the furnace doors. After cooling the ends of the wires, they were attached by a quick-acting connector *via* suitable leads to an indicating potentiometer.

When the test billet had passed a sufficient distance down the furnace hearth, the thermocouple wires were disconnected and pushed back into the furnace and then drawn out again at another door lower down the furnace. This operation was repeated until the billet reached the discharge position.

When the method was being developed, chromel/alumel wires were used, but this combination proved to be unsatisfactory, as the alumel wire failed repeatedly, owing to intergranular breakdown. After trying alternative materials, 14 S.W.G. heat-resisting

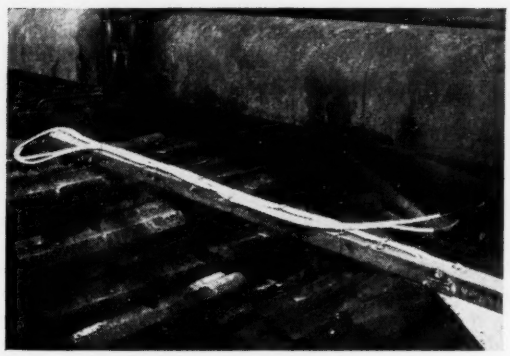
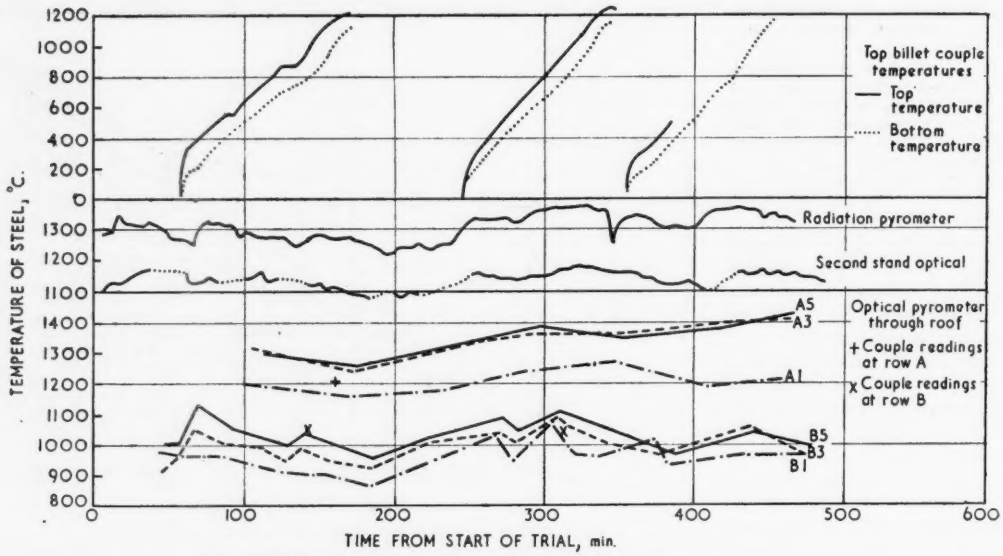


Fig. 8—Test billet ready for charging



Note. "Top billet couple temperature" should read "Test billet couple temperature"

Fig. 10—Summary of steel-temperature measurements: test 7 (3-in. billets)

wire with standard chromel wire was finally adopted and proved to be satisfactory.

The calibration of the wires which had passed through the furnace was checked on a number of occasions and found to be unchanged.

Optical-Pyrometer Readings after Second Stand—A common method of assessing steel temperature for rolling is by means of an optical pyrometer sighted on the steel in the mill as near to the furnace as possible, but preferably when the scale has been removed. A position after the second stand was found to be reasonably free from steam and was used for this purpose.

Comparison of Methods of Steel Temperature Measurement

The billet thermocouple method was developed and used not only to assess heat transfer and steel-temperature uniformity, but also as a primary method of measurement to calibrate optical and radiation methods which could give a more continuous record.

Optical Pyrometer Through Sighting Tube—Figure 9 shows the results of a preliminary billet-temperature test with the results of optical methods superimposed. For convenience of comparison all the optical readings (irrespective of the actual time at which they were taken) were plotted at the time on the test-billet curve corresponding to the position at which they were taken. It is shown that the common method of sighting an optical pyrometer through the doors on to the steel, even when the optical path is not obscured by flame, is very inaccurate at all points, except the hottest zones of the furnace.

By using an air-swept sighting tube to shield the target area from flame radiation, the error was of the order of 20° C. high in the hotter zones (the final 40% of hearth length) when the tube was touching the billet surface. This test was only one of several which showed an accuracy of $\pm$ 20° C. by this technique. In the main trials, it was not possible to maintain this accuracy owing to practical handling difficulties and the arduous conditions under which the observer had to work. The loss in accuracy was not, however, inherent in the method. The optical readings, compared with the couple readings taken during the short-period trials, showed an average error of 23° C. low at *B* and 33° C. high at *A* row. The errors were not very consistent and the results can only be used in a general way to show the average temperature distribution.

Figure 9 also shows that when the sighting tube was raised only 2 in. off the steel surface the error was increased by about 100° C. at *C* row, by 60° C. at *B* row, and hardly at all at *A* row. The error, in fact, corresponds closely to that obtained when an optical pyrometer is sighted through the furnace door.

Second-Stand Optical Pyrometer—It was found that the difference between the temperatures read by billet couples and those read by this method varied, the difference depending on the billet thickness and the rate of heating. The average difference (short-period trials) was 70° C. low and it can be predicted reasonably accurately from billet size.

During the short-period trials, the optical pyrometer through the sighting tube showed a temperature about 100° C. higher than that at the second stand. Thus, on the average, the optical pyrometer in the furnace read 30° C. higher and the second-stand pyrometer read 70° C. lower than the actual steel-surface temperature in the furnace.

Radiation Pyrometer—This was found to give a constant error for the two tests in which it was used and should be suitable as an automatic control instrument.

Table I

FACTORS AFFECTING FUEL CONSUMPTION

Billet Thickness, in.	No. of Recordings	Heating Rate, tons/hr.	Furnace Pressure, in. W.G.	Waste-Gas Flow (Fraction of Full Scale)	Total Corrected Gas Flow, 1000 cu. ft./hr.
1¾	9	10·33	0·032	0·23	92·4
2	136	17·74	0·028	0·38	127·1
2½	89	17·46	0·028	0·43	125·1
3	86	26·49	0·029	0·50	170·5
3½	12	25·88	0·014	0·65	177·0
4	12	28·28	0·018	0·73	213·0
Average for all billet sizes	344	20·31	0·028	0·45	141·5

To enable all these methods of temperature measurement to be compared, the results have been plotted on a time base for each test, and a typical chart for test 7 is given in Fig. 10. The diagram shows how closely the radiation pyrometer follows the optical readings taken in the mill, and also that the Rotherham side of the furnace is always cooler than the Sheffield side (lines *A*1 and *B*1 represent the Rotherham side).

Determination of Mean Billet Temperature (Short-Period Trials)

The average final billet-top temperature was estimated from the readings taken after the second stand in the mill. The difference between the latter temperature and the top temperature, as measured by the billet test couples, was determined and then this difference was added to the average temperature recorded at the second stand. For the last two tests, where a radiation pyrometer was sighted on the steel, it was discovered that the average of the radiation pyrometer and the second-stand optical readings was very close to the temperature recorded by the billet test couples. An average top temperature was therefore calculated by taking the mean of these throughout the last two tests.

The difference in temperature between the top and bottom of the billets could only be taken from the test-billet results, and an average of this difference from the three available readings per test was used. To enable the mean billet temperature to be calculated

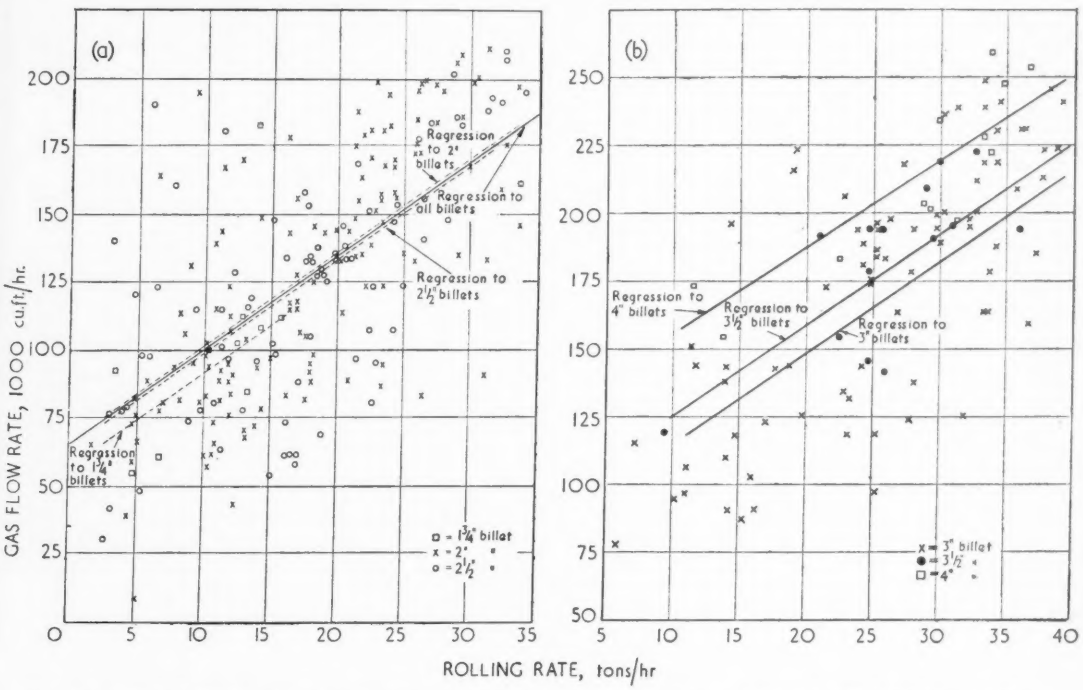


Fig. 11—Relationship between gas-flow rate and rolling rate (long-period trials): (*a*) Billet thickness below 3 in.; (*b*) billet thickness 3 in. and over

Table II

EFFECT OF VARIABLES ON FUEL CONSUMPTION

Billet Size, in.	No. of Recordings	Air Preheat Temp., °C.	Steel Output, tons/hr.	Gas Rate, 1000 cu. ft./hr.	Furnace Pressure, in. W.G.	Waste-Gas Flow (Fraction of Full Scale)	Waste-Gas Temp., °C.
1¾	9	70·6	10·33	92·4	0·031	0·23	274·4
2	130	166·7	17·11	123·2	0·028	0·39	449·9
2½	65	135·6	16·43	118·8	0·035	0·32	440·3
3	75	189·4	25·88	166·5	0·030	0·47	451·8
3½	12	274·6	25·88	177·0	0·014	0·65	489·6
4	12	293·3	28·28	213·5	0·018	0·73	522·1

from the average top temperature and the average temperature difference, it was assumed[1] that the temperature/depth curve is parabolic, in which case

$$t_m = t_t - \tfrac{2}{3}(t_t - t_b)$$

where t_m, t_t, and t_b are mean, top, and bottom temperatures, respectively. This assumption has been checked on an electrical heat-flow computor and shown to be sufficiently accurate.

Miscellaneous

The humidity was measured by a standard wet-and-dry-bulb thermometer located near the combustion-air fan inlet.

It was not practical to weigh all the steel charged during the short-period trials, and so the weight was obtained by measuring the length of each billet before it was charged and converting these measurements into weight from the weight per foot of billet. The latter was obtained by weighing sample batches of billets once per hour during the trials.

The steel output was obtained by weighing, and all scrap, cobbles, and crop ends were collected during the test period and weighed. The scale lost in the furnace and mill was estimated by difference.

A counter for recording the number of billets pushed out of the furnace is operated by the furnace crew, and this was read at 5-min. intervals.

FURNACE FUEL CONSUMPTION

The long-period trials showed that various factors in addition to the amount of steel heated affected the fuel consumption. The average values of some of the factors studied are shown in Table I.

Many other variables were examined (*e.g.*, the performance of the recuperator) but space considerations make it necessary to deal with only the more important ones.

Effect of Heating Rate and Billet Size

The steel output was found, as would be expected, to be strongly related to the gas rate. The relationships (long-period trials) for two billet-size groups are shown in Figs. 11*a* and *b*. It was found that the slopes of the lines for each billet size were not significantly different, and so the data were combined under a single slope drawn for each line. Thus, for each billet size a given increase in output requires the same increase in gas consumption. The relationship is calculated with the smaller effects of other variables eliminated, so that the lines for each billet size represent the gas-flow/output relationships at average values of these other variables.

For billets up to 2½ in., the thickness has no effect and a given output can be obtained at the same gas rate. For 3-in., 3½-in., and 4-in. billets, there is a considerable difference between the relationships for the various billet sizes, the gas flow being higher and the furnace efficiency lower with the thicker billets. Although the main factor affecting the rate of fuel consumption is the furnace throughput, efficiency is reduced when thicker billets are rolled.

If the gas consumption per ton of output is plotted against rate of output, the usual furnace-characteristic curves are obtained at different levels corresponding to the billet size.

The results of the short-period trials have been plotted in a similar way (*see* Fig. 12). There is a clear

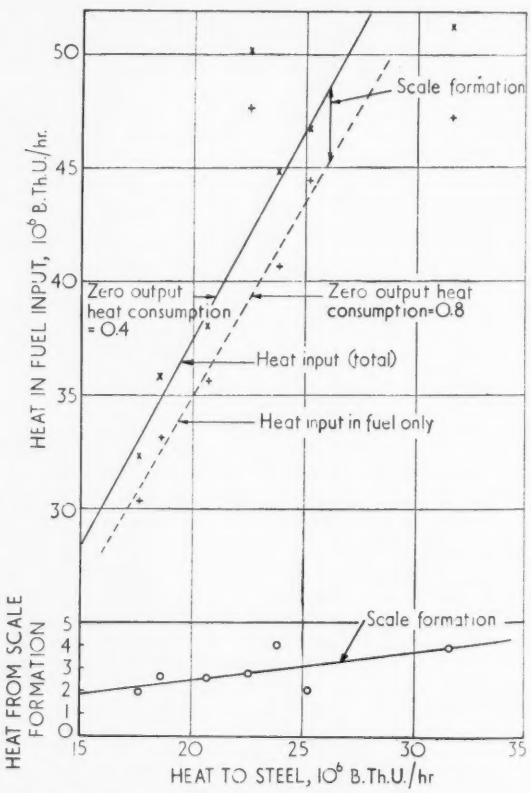


Fig. 12—Relationship between heat input and heat to steel

correlation between the heat of the fuel and the heat to the steel, but the main points to note are the very steep slopes and the fact that the lines, if extrapolated, pass almost through the origin, giving the impression that there is zero fuel consumption at zero output and constant efficiency at all loads. This, of course, cannot be true, as fuel is required to meet structural and associated flue-gas losses when the furnace is empty. This phenomenon is explained by reference to the relationships found in the long-period trials (Figs. 11*a* and *b*), where separate characteristic curves for each billet size were found; the larger billets required more gas to give the same rate of output. These curves were of a much smaller slope than the overall curve now considered. Since the chances of testing the furnace at or near the average operating point for that billet size are fairly high, the curve (Fig. 12) now considered approximates to a line of a much steeper slope, joining the means of the lines for individual billet sizes. This graph illustrates the need to account for billet thickness in an analysis of furnace performance.

Figure 12 also shows that the heat from scale formation correlates quite well with the heat to the steel and is almost a constant percentage of that quantity (12·5%).

Waste-Gas Temperature and Flow and Output Rates

With a view to explaining the variations in fuel-consumption rate with different loads and billet sizes, the average values of the variables shown in Table II were studied for each billet group during the long-period trials.

The relationship between waste-gas temperature measured before the recuperator and steel output for billets of 3 in. and over is shown in Fig. 13. Similar correlations were also found between waste-gas temperature and gas-flow rate. This is to be expected, since gas-flow rate and steel output are themselves related. The points plotted are the actual ones (other factors varying), but the lines drawn are corrected to the average waste-gas flow and furnace pressure for each billet size, in order to study the independent effect of output rate.

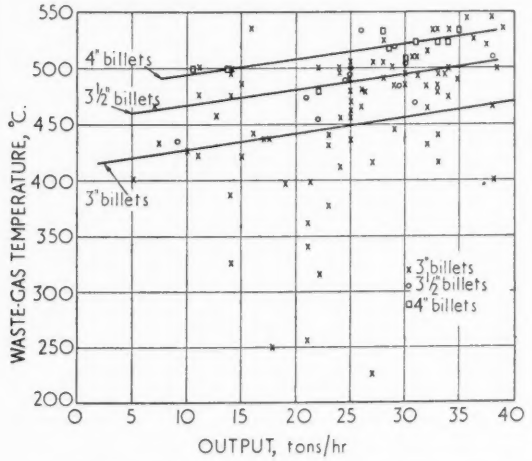


Fig. 13—Effect of rate of output on waste-gas temperature (billets 3 in. and over)

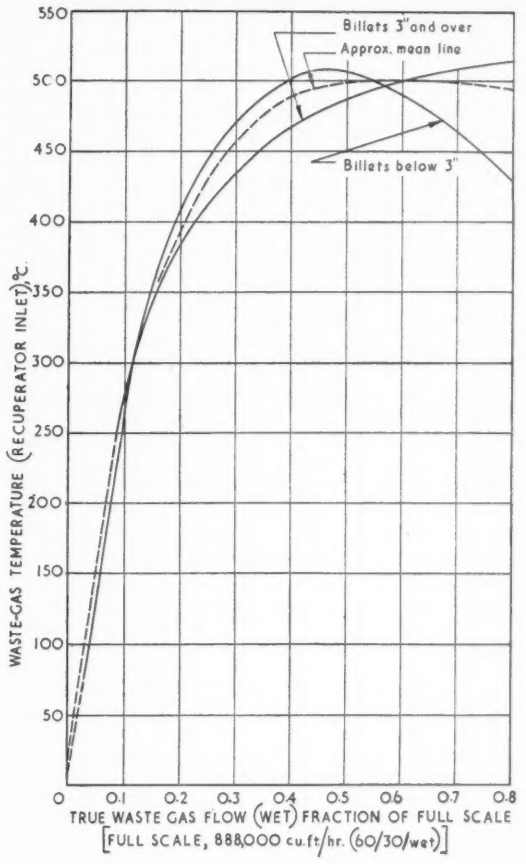

Billets 3" and over
Approx. mean line
Billets below 3"
WASTE-GAS TEMPERATURE (RECUPERATOR INLET), °C.
TRUE WASTE GAS FLOW (WET) FRACTION OF FULL SCALE
[FULL SCALE, 888,000 cu.ft/hr. (60/30/wet)]

Fig. 14—Waste-gas flow/temperature relationship

Higher outputs are associated with higher waste-gas temperatures and the curves are similar to those for fuel consumption *vs.* output, in that there are different levels for billets of different thicknesses, the waste-gas temperature being higher for thicker billets at constant output or gas-flow rates.

The average values of waste-gas flow and furnace pressure do, however, differ between billet groups, and if the lines in Fig. 13 are further corrected so that they all represent conditions at the same waste-gas flow and furnace pressure, the difference between billet groups disappears. This means that the larger billet sizes, even at the same rate of output, carry higher waste-gas flows, owing to lower furnace pressure and higher gas flow, which, in turn, result in the waste-gas temperature being higher.

The relationship between waste-gas temperature and waste-gas flow is shown in Fig. 14. The shape of the curves can be understood when it is remembered that increasing waste-gas flow is due to lowered furnace pressure and increased gas flow. On smaller billets it will be shown to be almost entirely dependent on

furnace pressure; *i.e.*, an increase in waste-gas flow is largely due to increased infiltrated-air quantities resulting from lowered furnace pressures. Excess air can either increase or decrease the waste-gas temperature. It reduces the combustion temperature, lowers the rate of heat transfer, and increases the waste-gas temperature in certain circumstances, whereas in others the cooling effect of the air lowers the waste-gas temperature. It is conceivable that with the low waste-gas flow associated with higher furnace pressure, which gives small amounts of excess air entering only near the combustion zone, the first effect (*i.e.*, a lowering of the flame temperature and heat-transfer rate) would be predominant and the waste-gas temperature would increase with rising waste-gas flow. As the furnace pressure falls and the waste-gas flow increases, the quantity of infiltrated air increases and more of it is admitted further back in the furnace. Then the second effect could take over and result in a lowering of the waste-gas temperature with high waste-gas flows and low furnace pressures. The shape of the curve will also be affected by heat loss between the furnace outlet and the gas-temperature measuring point before the recuperator, the temperature drop being greater at low flows than at high ones. There is a relationship (not illustrated) between furnace pressure and waste-gas temperature, but this only reflects the effect of furnace pressure on waste-gas flow.

The overall relationship for all billet sizes between waste-gas flow to the recuperator and furnace pressure is shown in Fig. 15. This shows the waste-gas flow falling linearly as the furnace pressure is increased. A high furnace pressure results in waste gas being lost from the furnace chamber, and a low furnace pressure causes air infiltration. The scatter is large, but the points for the large billets lie towards the top of the band. Some other factor connected with billet size thus influences waste-gas flow on the larger billet sizes. This is not surprisingly found to be the gas flow, and equations involving both factors are:

$$W = 70{\cdot}5 - 1{\cdot}13P \text{ (below 3-in. billets)}$$
$$W = 69{\cdot}5 + 0{\cdot}12G - 1{\cdot}37P \text{ (billets 3 in. and over)}$$

where W = Waste-gas flow, % full-scale meter reading
P = Furnace pressure, 10^{-3} in. W.G.
G = Producer-gas flow, 10^3 cu. ft./hr.

It will be noted that gas flow only significantly affects the volume of waste gases passing to the recuperator when heating thick billets.

During the short-period trials, the waste-gas temperature measured before the recuperator has been

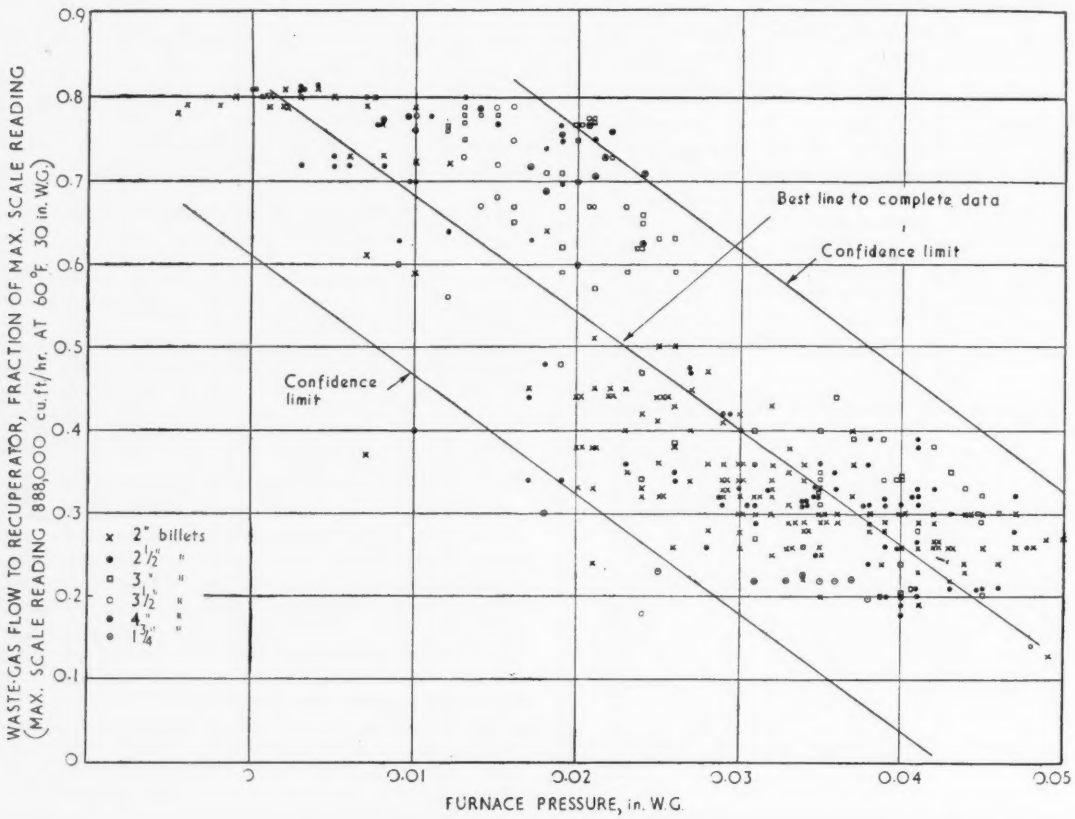


Fig. 15—Furnace-pressure/waste-gas-flow relationship

plotted against various factors, and the best correlation obtained was with producer-gas flow, the temperature rising as the producer-gas flow increased. The furnace pressure, air/gas ratio, and gas per ton of steel gave no significant correlation, but there was an indication that the waste-gas temperature rose as the waste-gas flow increased, as observed during the long-period trials. The range of furnace pressure used was much less in the short-period trials.

The waste-gas flow to the recuperator was also found to depend on producer-gas flow and billet size, reaching a maximum of about 500,000 cu. ft./hr. under the conditions of furnace pressure obtaining during the tests. There was also an indication of a downward trend in waste-gas flow with increasing furnace pressure, but this was not definite, owing to the narrow range of furnace pressures used.

Hearth Utilization

The percentage hearth utilization (ratio of billet length to width of furnace) varied from 81% to 88%, with an average of 84·8%. If billets were supplied at the maximum length (30 ft.), an average increase in output of 9·4% (3·3–15·8%) would be possible (first approximation). This theoretical increase in output would only be approached on the larger billets, as the furnace can heat the smaller sizes faster than the mill can roll them. This is, however, an economic problem in which other parts of the plant are involved.

The average scale formation was 1·8%, and the scrap and crops averaged 2·75% of the charged weight.

FURNACE PRESSURE

Overall Effect of Furnace Pressure

Preliminary measurement revealed that the waste-gas damper was not used very effectively, and that the furnace pressure was generally very low on small outputs (small sizes) and higher, owing to the increased gas flow, when heating thicker billets. For the long-period trials, a recorder was fitted and the furnacemen were instructed to regulate the damper according to the gas flow being carried. Table I shows that the average furnace pressure still varied and was generally lower on the larger billet sizes, indicating the reluctance of the furnacemen to carry a high furnace pressure when heating such billets. This was due to a tendency to air shortage at the high gas rates and a fear of burning billets if the flame were too hot at the discharge end of the furnace; it probably reflects the unsuitability of the furnace for heating thick billets at high rates of output.

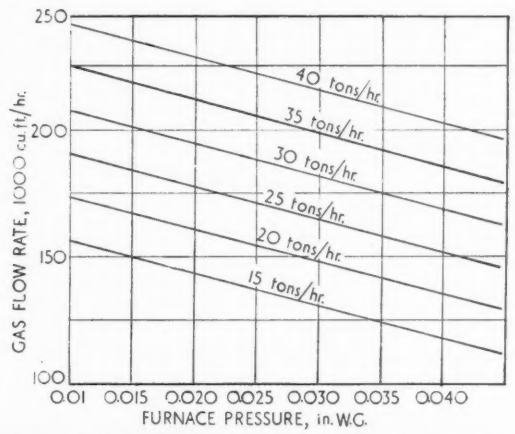


Fig. 16—Relationship between furnace pressure, output, and gas-flow rate (billets 3 in. and over)

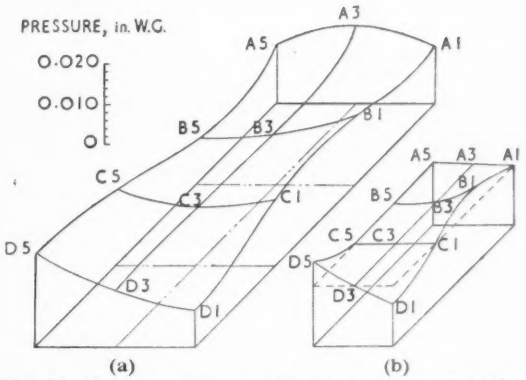


Fig. 17—Furnace pressure distribution at roof (high-gas-flow, damper open)

It was at first assumed that the correct furnace pressure to use was that necessary to bring the zero-pressure line down to the mean hearth height (0·04 in. W.G. in this case). Statistical examination of the long-period data enabled Fig. 16 to be constructed for the large billets; it shows no optimum pressure. Here open-damper conditions can result in fuel wastage of 15% in comparison with operation at 0·04 in. W.G. Automatic damper control cannot claim 15% saving over intelligent hand control, but it can claim this saving over the original practice of leaving the damper wide open, which resulted in low furnace pressure, even on the larger sizes.

The furnace pressure during the short-period trials was not varied very much, owing to the controller being used. Some indications of the effect of the pressure are, however, considered in the section on combustion.

Furnace-Pressure Distribution

The pattern of pressure distribution throughout the furnace was studied in a supplementary trial. This work helped in the selection of pressures to be used for the main short-term trials and indicated the most suitable position in the furnace for the automatic pressure-controller measuring point. In this work statistical techniques were used, so that random variation should not be confused with a change of pattern.

The furnace pressure was measured at the roof, at columns 1, 3, and 5 as shown in Fig. 4, using a micromanometer. Reference readings were also taken on a fixed recorder. The furnace-pressure distribution was examined under four conditions:

Low-Load Test: (i) Low gas flow, damper controlled to give specified roof pressure
(ii) Low gas flow, damper fully open
High-Load Test: (iii) High gas flow, damper controlled to give specified roof pressure
(iv) High gas flow, damper fully open.

The furnace-pressure distribution followed the same general form in all four cases. Figure 17*a* shows the results for high gas flow with the damper fully open. Considering the whole furnace, there was no significant difference in the average pressure across the furnace, and on only one occasion was there an indication of a difference along the furnace. Figure 17*b* shows the significant variations from the average pressure level which occurred at individual points. At *D* row or the charge end of the furnace, there was a persistent variation of pressure across the furnace, *D*1 being low and *D*5 high. There were other extremely high and low pressure points in the furnace, and these alter with changing conditions of operation. These peculiarities were, with one exception, near the side walls, the centre of the furnace being free from such effects. Position *B*3 was thus shown to be a suitable point for recording or controlling the pressure and was used for this purpose during the short-term trials.

Assuming a tight furnace with an equal distribution of flow to the gas, air, and waste-gas ports, there should be no variation of pressure across the furnace at right-angles to the direction of gas flow. This was found to be the case, except for isolated points.

Moving along the furnace from the hot end to the cold end, pressure variations would be expected for a variety of reasons. Firstly, there will be a drop of pressure from one end to the other, due to friction in the furnace and to increasing velocity head. Therefore, if the furnace roof were flat there would be a steadily decreasing pressure towards the cold end of the furnace. In practice the roof is only flat up to a point just beyond row *B*, when it starts to rise. The effect of this rise will be to increase the pressure at the roof. The results of the first test with low gas flow confirmed the theory; the pressure fell to row *B* and then increased to row *C*, decreasing slightly again at row *D*. In the last three tests, however, the opposing effects cancelled each other, so that the general effect is a constant pressure from end to end of the furnace.

The effect of doors being open or leaking will be different according to the pressure at the particular point in the furnace. If the pressure at the door (not the roof) is lower than atmospheric, air will leak in, causing an increase in volume and in pressure. If, on the other hand, the furnace pressure is greater than atmospheric at the door, the gases will leak out and result in a slight drop in pressure at that point. Another disturbing factor is that the gas and air ports point vertically upwards and some velocity head may be registered at the *A* row of holes. The exceptional points can be explained to some extent by these facts.

The low pressure at *D*1 (Fig. 17) can be explained

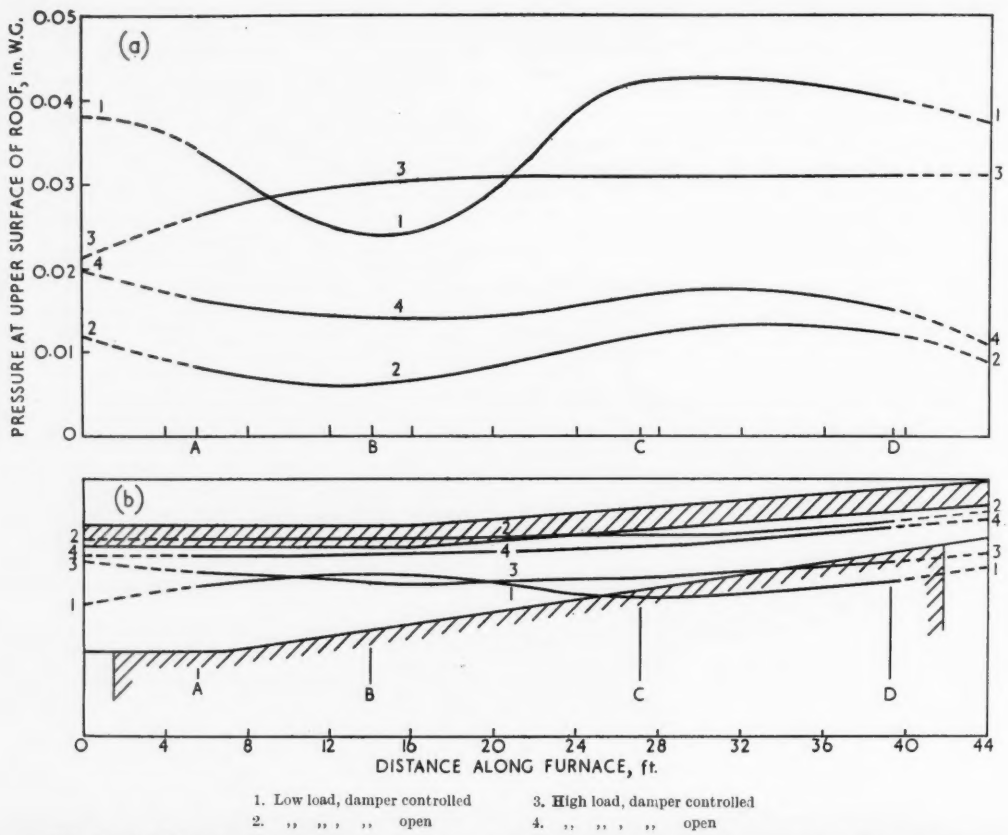


Fig. 18—(*a*) Distribution of furnace pressure and (*b*) position of zero-pressure line in furnace

by there being three doors permanently open at this point; the gases can escape through them, resulting in reduced pressure.

By taking the average furnace pressure (at the roof) for each row and the combustion-gas temperature at that point, the buoyancy head at each station can be calculated, and thereby the position of the neutral point (zero pressure). Figure 18 shows these positions on an outline of the furnace, and also the average furnace pressures at each row. It shows that under 'damper-open' conditions most of the furnace chamber is under suction, allowing considerable air inleakage.

Ideally, the heat loss by blow-out of hot gas and air infiltration is at a minimum when the zero-pressure line is approximately on the door sill. With a furnace of this type this condition is impossible to attain, because lowering the zero-pressure line at the hot end will result in excessive pressure at the cold end. It would appear at first sight that this line should be lowered so that it is on the door sill at the middle door, giving a negative pressure at the hot end and a positive at the cold end. However, loss by blow-out is not so serious as loss by air infiltration, and this factor will tend to make the best position of the zero-pressure line lower, thus reducing the area subject to air infiltration. On the other hand, excessive blow-out tends to result in a lowered recuperator performance, because the volume of gas supplied to the recuperator is reduced.

It would thus appear that a somewhat higher pressure than obtained during these supplementary trials would be beneficial to furnace operation.

COMBUSTION

The data reported in this section all arose from the short-period trials, and combustion has been studied by an examination of the metered volumes of gas and air and by gas analyses taken in the furnace chamber and in the flues.

Air Leakage in Recuperator

Figure 19 illustrates the conditions that were found when the furnace was tested, namely, that considerable leakage occurs from the air to the waste-gas side of the metallic recuperator. Attempts were made before the tests began to reduce this leakage by blanking-off some of the faulty tubes, but even after

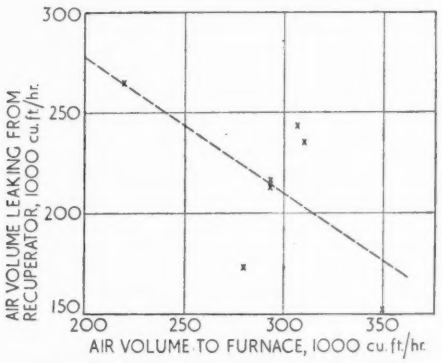


Fig. 19—Air leakage in recuperator

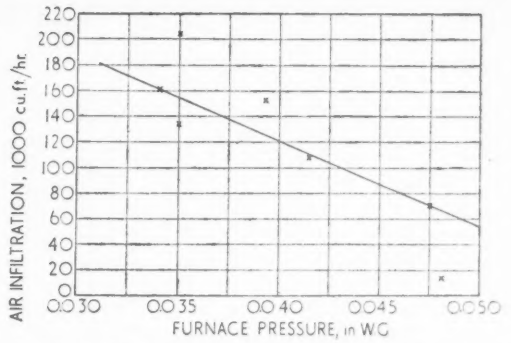


Fig. 20—Effect of furnace pressure on air infiltration in furnace chamber

these repairs the leakage could amount to 42% of the air delivered by the fan. Further improvement would have necessitated complete retubing, and time was not available for this to be done. The curve shows that leakage decreases when more air is delivered to the furnace, owing to the pressure on the air side being reduced as the air-control valve is opened. These effects reduce the efficiency of the recuperator considerably and in some circumstances cause a shortage of air at the furnace.

Furnace Pressure and Air Infiltration into Furnace Chamber

The amount of air infiltration into the furnace chamber, even though the furnace pressure was controlled to quite a high value, is considerable, and on the average was 29% of the total air entering the furnace (including air infiltration) or 41% of the measured air to the furnace. Figure 20 shows that this infiltration is very dependent on the furnace pressure, being reduced when the pressure is higher. The infiltration with the present furnace could be reduced to a very small figure by operating at about 0·055 in. W.G., but in these circumstances the gas blown out from the furnace chamber might be excessive. More hot air would also be required, and with the present recuperator it would not always be available.

Air/Gas Ratios and Excess Air

The more important factors related to air/gas ratios and excess air are given in Table III, which shows that the hot air is delivered to the furnace in almost theoretical proportion, the average of all tests showing only 5% excess of air, although some tests did show a slight deficiency. This does not mean, however, that a nearly theoretically correct proportion is delivered to the burners, as some of the metered air passes to the furnace *via* the secondary air ports in the roof and front wall. Even in the test on small billets, when the secondary air slides were closed, some air would pass as a result of leakage. There is thus a slight deficiency of air at the burners, resulting in a combustion rate lower than the maximum possible. This deficiency becomes more serious as the producer-gas flow increases, resulting in inefficient combustion and long flame conditions. The latter are, however,

Table III
AIR RATIOS AND EXCESS AIR

Test No.	1	2	3	4	5	6	7
Billet size, in.	2	3	2⅛	4	3½	2½	3
Gas flow, 1000 cu. ft./hr.	158	233	149	179	230	186	215
Theoretical air volume per cu. ft. of gas	1·475	1·441	1·467	1·443	1·471	1·539	1·470
Measured air/gas ratio	1·390	1·500	1·880	1·645	1·275	1·667	1·423
Excess (+) or deficiency (−) of preheated air, % of theoretical	−5·76	+4·10	+28·15	+14·00	−13·33	+8·33	−3·30
Air/gas ratio at furnace exit (including air infiltration)	1·830	1·965	2·960	2·400	2·160	1·745	2·135
Excess air at furnace exit, %	24·1	36·4	101·7	66·7	46·8	13·4	45·2

necessary with the present design, especially when heating thick billets, so as to transfer heat further back in the furnace and avoid overheating the steel on the soaking hearth near the discharge point. The fall in air/gas ratios at higher gas rates may be partly due to a shortage of air at the higher gas rates and also to the furnaceman trying to lengthen the flame when heating thicker billets. It is difficult when heating such billets at high gas rates to keep the heat transmission low in the hearth area near the burner ports and yet to increase it in the upper zones. Furthermore, having initiated long flame combustion, it is difficult to complete it before the gases leave the furnace without adding large quantities of excess air. This is one of the limitations of the existing furnace. For the most efficient combustion and rapid heat transfer combustion should be completed with a slight excess of air as quickly as possible, but with end burners this will result in overheating of the steel and bad steel-temperature uniformity. These difficulties could be overcome to a large extent by the use of two-zone firing, where the soaking hearth and the main body of the furnace are separately fired; this is discussed later.

Table III shows that the excess air at the furnace exit is reasonably small (about 50% on the average), although it is variable. It could not be economically reduced on the existing furnace, as a higher furnace pressure would result in excessive blow-out and a deficiency of air at the burner ports, especially when heating larger billets.

Combustion Gas Lost by Blow-Out

The blow-out volume or the volume of furnace gases forced out of the furnace chamber has been determined by the difference between the total volume of combustion products as calculated from the gas burned and the composition of the flue gas before the recuperator, and the metered waste-gas flow entering the recuperator.

This blow-out volume is shown to be very high and variable, being on average 27½% of the total combustion gas generated in the furnace. A reduction in this loss would effect savings in two ways. Firstly,

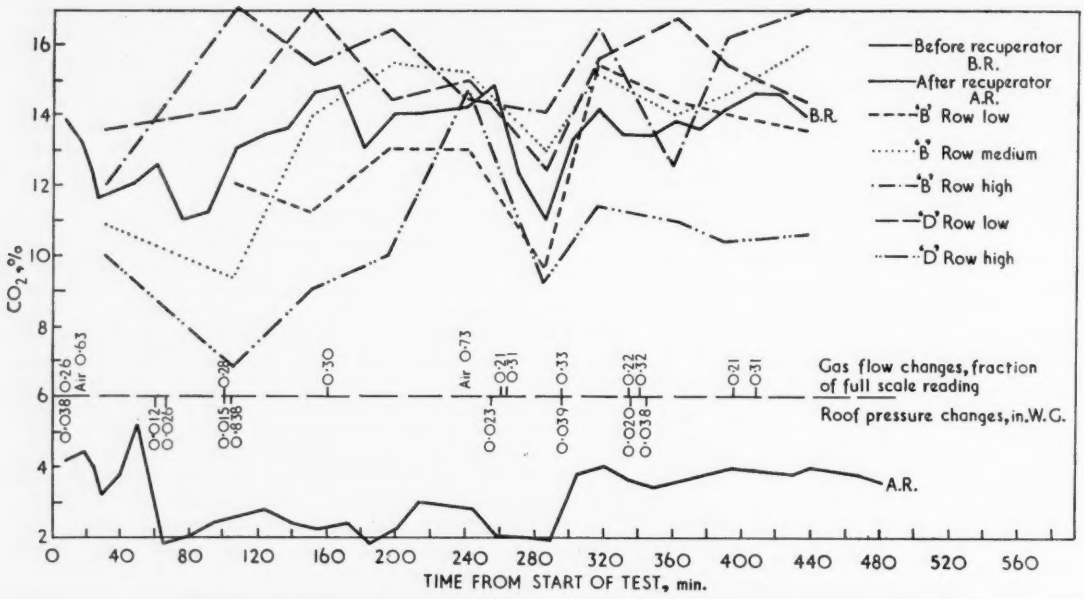


Fig. 21—Variation in CO_2 content of combustion gases: test 3 (2½-in. billets)

the gas would do more useful work in heating the steel, and, secondly, more waste gas would be available to preheat the air. A reduction in the blow-out volume by lowering the furnace pressure would, however, defeat its own object, as the air infiltration would increase.

It is evident from the foregoing that the furnace structure should be made more gas-tight. This would reduce air infiltration and blow-out on its own account and would also permit a higher furnace pressure to be carried, reducing air infiltration still further without causing excessive blow-out. These improvements are, however, only possible if more preheated air is made available to the burners by means of an air-tight recuperator.

Progress of Combustion

The progress of combustion in the furnace system was followed by analysing the gases at selected points (*B*3 and *D*3, in Fig. 4) and at different levels, as previously described.

Figure 3 shows that the air, after following a tortuous path, is finally ejected into the gas port just below the bridge wall, the air stream being perpendicular to the gas stream at this point.

The burning gas–air mixture is projected vertically upwards along the front wall and thus along the roof. Secondary air can be injected either along the front wall or through the roof some distance back from the ports (*see* Fig. 2).

A typical record of the CO_2 analyses for test 3 is given in Fig. 21. The CO_2 content in any one position varies considerably, presumably owing to the variable nature of the flow and the consequent heterogeneity of the furnace gases. In most cases changes are reflected throughout the furnace system to a greater or lesser degree. The changes in CO_2 content often correspond to times when test billets for temperature measurements were charged, the furnace pressure being reduced and the gas turned down for this operation. Other periods of low CO_2 correspond to stoppages when the gas was turned down. Whilst CO_2 only is shown in this diagram, oxygen and CO contents were also determined. The oxygen varied inversely as the CO_2, and the CO varied from zero to 3–4% at *B* row and from zero to 2% at *D* row, being insignificant at the recuperator inlet.

The distribution of the combustion gases in the furnace chamber is of interest in visualizing the progress of combustion and gaseous flow. The trends noticeable in Fig. 21 are more clearly shown by studying the mean values given in Table IV.

In the *B* and *C* rows, the lowest CO_2 is usually at a point nearest the hearth, but at *D* row at the back of the furnace the lowest CO_2 is nearest the roof. The low CO_2 near the hearth is explained by air infiltration being greater at hearth level and by the flame being directed under the roof. The reason for the CO_2 being higher near the hearth at *D* row is probably that there is no air infiltration at this point, and the secondary air which enters through the roof thus tends to lower the CO_2 at the higher levels. The probes were always on the centre-line of the furnace, so that the effect of air infiltration should be a minimum. The stratification nearer the side walls would be much more severe.

The overall effect of height in the furnace and distance along the furnace from the burners is shown

Table IV
COMBUSTION-CHAMBER ANALYSES

Row	B				C				D			Overall Average
Position	High	Medium	Low	Av.	High	Medium	Low	Av.	High	Low	Av.	
Carbon Dioxide, %												
Test 1	—	—	—	—	16·35	15·73	15·00	15·70	—	—	—	15·70
2	—	—	—	—	15·60	14·85	15·20	15·20	—	—	—	15·20
3	15·14	13·75	12·9	13·96	—	—	—	—	10·31	14·88	12·60	13·39
4	14·47	14·55	13·60	14·20	—	—	—	—	15·20	14·16	14·61	14·39
5	14·12	14·77	12·73	13·85	—	—	—	—	14·12	14·87	14·50	14·13
6	11·72	14·42	10·56	12·23	—	—	—	—	15·18	15·40	15·29	13·45
7	14·48	13·24	12·45	13·39	—	—	—	—	14·44	14·19	14·32	13·76
Average	13·97	14·15	12·45	13·52	15·96	15·29	15·10	15·45	13·86	14·70	14·27	14·14
Oxygen, %												
Test 1	—	—	—	—	1·22	1·42	1·77	1·46	—	—	—	1·46
2	—	—	—	—	1·07	1·24	0·84	1·05	—	—	—	1·05
3	2·54	3·06	4·20	3·24	—	—	—	—	6·68	2·44	4·56	3·78
4	2·73	2·03	3·42	2·73	—	—	—	—	2·60	3·25	2·96	2·81
5	2·12	1·53	3·24	2·27	—	—	—	—	3·30	2·52	2·91	2·54
6	3·86	2·28	6·53	4·22	—	—	—	—	2·44	2·31	2·38	3·49
7	1·76	3·29	3·98	3·01	—	—	—	—	2·22	2·15	2·19	2·68
Average	2·60	2·44	4·28	3·11	1·15	1·33	1·31	1·26	3·45	2·53	3·00	2·71
Carbon Monoxide, %												
Test 1	—	—	—	—	0·80	1·03	0·85	0·90	—	—	—	0·90
2	—	—	—	—	0·73	0·91	0·76	0·80	—	—	—	0·80
3	0·66	0·87	0·73	0·75	—	—	—	—	1·05	0·58	0·82	0·78
4	0·27	0·24	0·18	0·23	—	—	—	—	0·14	0·33	0·25	0·23
5	0·24	0·29	0·12	0·22	—	—	—	—	0·14	0·40	0·27	0·24
6	1·65	1·95	1·18	1·59	—	—	—	—	0·26	0·43	0·35	1·10
7	1·26	0·76	1·18	1·07	—	—	—	—	0·94	0·69	0·82	0·97
Average	0·82	0·82	0·68	0·77	0·77	0·97	0·81	0·85	0·51	0·49	0·50	0·70

Averages of All Points

	High	Medium	Low
CO_2	14·28	14·50	13·83
O_2	2·71	2·12	3·05
CO	0·68	0·86	0·62

Averages of High and Low Points from Positions B and D

	High	Low
CO_2	13·92	13·57
O_2	3·03	3·40
CO	0·66	0·58

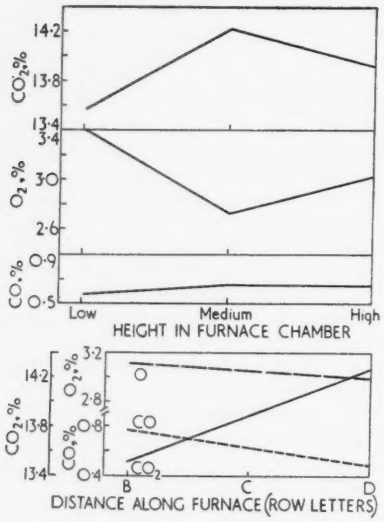


Fig. 22—Progress of combustion

in Fig. 22. The top three curves show the CO_2 to be lowest nearest the hearth and highest half-way up. The line for oxygen content is as expected and the CO is lowest where the oxygen is highest.

The bottom set of curves show the progress of combustion along the furnace. At *B* row, combustion has reached an advanced stage, with less than 0·8% CO on the average, although visible flame is nearly always apparent at this point. At *D* row, where there is usually no visible flame, the CO has fallen slightly, being accompanied by a fall in oxygen content and a rise in CO_2 as the combustion proceeds.

The relation between the CO_2 level at the recuperator inlet and the composition of the furnace gases is shown in Fig. 23. Test averages at each point are plotted. There is a straight-line relationship between the CO_2 at the back of the furnace at *C* and *D* rows and that at the recuperator inlet, and there are similar relationships between oxygen and CO in the furnace with CO_2 before the recuperator.

The analysis at *B*3 (15 ft. from the burners) does not give the same form of line when plotted against this value. The CO_2 is a maximum when the CO_2 at the recuperator is about 12%, falling off when the latter quantity either increases or decreases. The oxygen and CO are both high when the CO_2 at *B* row is low, as compared with high oxygen and low CO occurring together when the analyses are taken at the back of the furnace. This is explained by the fact that when the CO_2 at the recuperator is less than about 12%, combustion is virtually completed at *B* row and the CO_2 falls at the back of the furnace, as a result of subsequent air infiltration. At CO_2 contents higher than 12% at the recuperator, combustion is incomplete at *B* row and the CO_2 at the back increases owing to further combustion, by as much as 3½% over the *B* row value when the CO_2 before the recuperator is 15·5%. The oxygen under these conditions falls about 3%, but the decrease in CO is insufficient to account for the CO_2 increase. Since the analyses were only taken at the centre-line of the furnace, this is not considered to invalidate the general conclusions, and there would, of course, be some combustion of carbon particles. It is thus demonstrated that the present port system is incapable of effecting rapid combustion, unless furnace pressure or air/gas ratios are held at inefficient levels.

In addition to this fault, the burners are unnecessarily complicated and, furthermore, they direct the flame towards the roof, resulting in inefficient use of the combustion space, infiltration of air, and stratification of combustion gases. They also necessitate water-cooling of the roof and the gas dampers. The existing ports should therefore be redesigned, or turbulent-type burners should be fitted, directing the flame between the roof and the stock. The latter would be preferable, and for two-zone firing would be essential.

The CO_2 before the recuperator was, on average, 1¼% less than at the back of the furnace, demonstrating that the CO_2 content at the sides was less than that measured in the middle of the furnace, the mixing before the recuperator causing most of the fall.

Figure 24 shows that with the furnace pressure at about 0·050 in. W.G., the difference (and thus the cross-furnace stratification) was negligible. The homogeneity of analysis inside the furnace was also

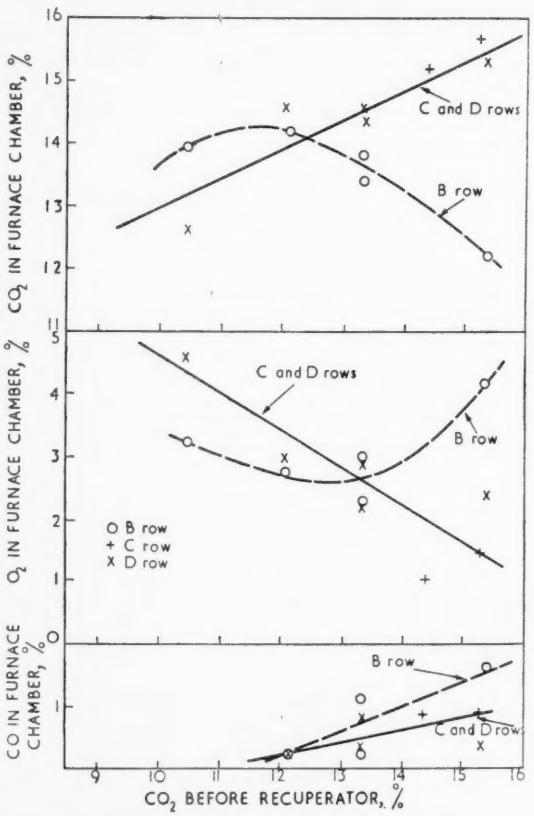


Fig. 23—Relationship between CO_2 content at recuperator inlet and conditions in furnace chamber

improved at higher roof pressures, owing to reduction of air infiltration.

Variation in Overall Combustion Efficiency

The overall level of combustion efficiency can be defined by the CO_2 content of the gases leaving the furnace chamber, provided that the combustible content is low. Since there is a good correlation between the CO_2 at the furnace exit and that at the recuperator inlet, the latter has been used, for reasons of convenience, as the criterion for a study of the effect of furnace variables on the combustion efficiency. The test averages were used for this purpose. Figure 24 shows that the CO_2 increased with rising furnace pressure and decreased with rising air/gas ratio, the correlation with furnace pressure being the better of the two. An increase in average furnace pressure from 0·034 in. W.G. to 0·048 in. W.G., resulted in the CO_2 leaving the furnace increasing from 12% to 15·5%. The change in CO_2 with changing air/gas ratio is, of course, to be expected, but the magnitude of the CO_2 variation with fairly small changes in furnace pressure demonstrates most forcibly the great importance of close control of this variable and the correct choice of the controlled value. If this furnace were made tight to avoid excessive blow-out, the pressure should be controlled in the region of 0·05 in. W.G. It has also been previously shown (*see* Fig. 20) that at this pressure air infiltration will be quite small.

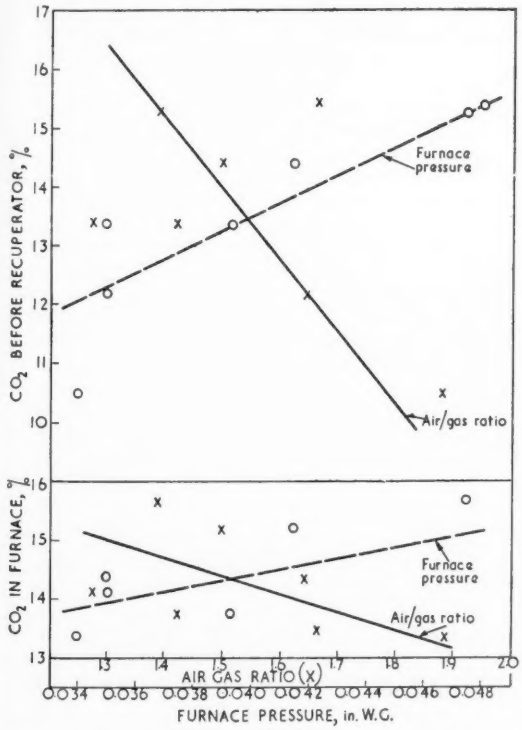


Fig. 24—Effect of air/gas ratio and furnace pressure on combustion

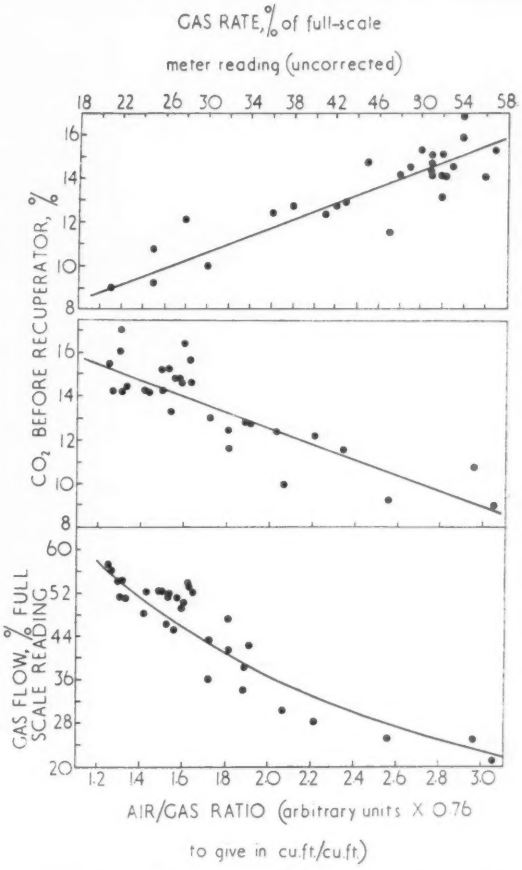

GAS RATE, % of full-scale meter reading (uncorrected)
CO₂ BEFORE RECUPERATOR, %
GAS FLOW, % FULL SCALE READING
AIR/GAS RATIO (arbitrary units X 0·76 to give in cu.ft/cu.ft)

Fig. 25—Variation of CO_2 content with other factors during test 5

The correlation between gas flow and CO_2 (test averages) was not very good, but plotting of the individual points for each test showed that combustion efficiency does depend on the gas flow. The individual results plotted in Fig. 25 for test 5, which showed considerable variations in gas flow and air/gas ratio, illustrate the point. This reflects inadequate control devices or defects in operation. The remedy for one of the faults is to fit air and gas meters, giving full instruction to the furnacemen on their use. Automatic air/gas ratio control would be better still. The air control could be improved by installing a tight-fitting valve in the secondary-air branch and a master valve upstream of the branch.

It was not proved whether the secondary air through the roof is effective in improving combustion conditions.

The heat loss in the waste gas passing to the recuperator and lost as blow-out was found to vary from 22% to 32% of the heat input with a variation of CO_2 from 15·5% to 10·5%. As no optimum final CO_2 has been found, the furnace should be worked as near to 15·5% as possible. Above that figure the loss may increase owing to the presence of combustible gases.

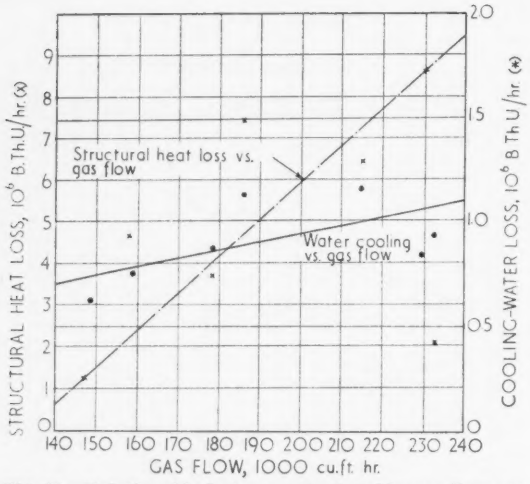

Structural heat loss vs. gas flow
Water cooling vs. gas flow
STRUCTURAL HEAT LOSS, 10⁶ B.Th.U/hr. (x)
COOLING-WATER LOSS, 10⁶ B Th U/hr (•)
GAS FLOW, 1000 cu.ft. hr.
0 1 2 3 4 5 6 7 8 9
0 0·5 1·0 1·5 2·0
140 150 160 170 180 190 200 210 220 230 240

Fig. 26—Relationship between structural losses (furnace only) and gas flow

HEAT BALANCES

Method of Calculation

The heat balances were calculated on two bases:

(i) For the furnace alone
(ii) For the furnace and recuperator together.

Simplified forms of the heat balances are shown in Table V. In Table V*a* the heat input includes the sensible heat of the hot air, and the waste-gas loss is calculated on the conditions before the recuperator. In Table V*b* the hot air is not included in the heat input, and the waste-gas loss is calculated on the conditions after the recuperator. The percentages quoted are based on the total heat input, including that from scale formation in the furnace. Since heat balances are sometimes based on the heat from the fuel only, and so appear to give better efficiencies, the figures resulting from using the latter method are also shown at the bottom of Table V*b*. On the average, neglecting the scale formation gives an apparent increase of efficiency of 3·8%. An important aspect, both from the practical point of view already discussed and because of its influence on the heat balance, is the magnitude of the loss due to blow-out of gases from the furnace chamber. If the waste-gas loss had been determined by assuming that all the waste gas is lost at the waste-gas flue temperature, the total loss would have appeared to be much smaller, resulting in the losses by convection and radiation from the furnace, determined by difference, being too large. Even when a separate blow-out item is included, as in these balances, there is no certain way of estimating the temperature at which this gas is lost. Although this treatment is an improvement on the simpler method, errors affecting the radiation loss can still be present.

In addition to these errors, serious mistakes can arise in recuperator calculations if it is assumed that all the waste gas generated passes to the recuperator.

Structural Measurements

The loss to cooling water and also the radiation loss from the furnace structure and unaccounted loss tend to rise with increased gas flow, as shown by Fig. 26. This apparent increase in structural loss at higher gas

Table V

SIMPLIFIED HEAT BALANCES, % OF HEAT INPUT

Test No.	1	2	3	4	5	6	7
Billet Size, in.	2	3	2½	4	3½	2½	3
(*a*) FURNACE ONLY							
Heat Input:							
(i) In fuel	90·63	87·04	88·90	87·75	90·06	86·98	91·67
(ii) In hot air	2·16	5·64	5·33	5·82	4·78	4·28	4·01
(iii) In scale formation	7·21	7·34	5·83	6·53	5·25	8·74	4·26
Heat Output:							
(i) To steel (efficiency)	50·71	57·93	51·39	50·83	42·51	50·86	51·76
(ii) Waste gas to recuperator	16·66	23·54	25·55	28·74	22·08	21·31	20·53
(iii) Blow-out gas	17·75	12·87	17·12	9·09	17·48	9·47	11·98
(iv) Cooling water	2·08	1·73	1·84	2·18	1·60	2·43	2·38
(v) Structural losses and errors	12·80	3·93	4·10	9·16	16·33	15·93	13·35
(*b*) FURNACE AND RECUPERATOR							
Heat Input:							
(i) In fuel gas	92·63	92·22	93·84	93·02	94·47	90·89	95·58
(ii) From scale formation	7·37	7·78	6·16	6·98	5·53	9·11	4·42
Heat Output:							
(i) To steel (efficiency)	51·75	61·46	54·39	54·23	44·73	53·16	53·77
(ii) To waste gas leaving recuperator	12·43	18·84	19·18	22·04	19·46	14·31	15·19
(iii) Blow-out gas	18·15	13·66	18·10	9·71	18·42	9·89	12·44
(iv) Cooling water	2·12	1·83	1·95	2·34	1·69	2·54	2·48
(v) Structural losses and errors	15·55	4·21	6·38	11·68	15·70	20·10	16·12
Heat to steel (neglecting scale formation)	55·9	66·7	57·8	57·8	47·1	58·4	56·4

flows and billet sizes may be due to the furnace being hotter at the back under these conditions and perhaps partly to an increased radiation loss through the doors, etc. The water-cooling loss will rise as a result of the higher gas temperatures at the water-cooled dampers and possibly as a result of higher roof temperatures in the water-cooled zones.

The heat loss to the cooling water is fairly constant, but the loss from the brickwork determined by difference is very variable. This is because the brickwork loss includes, as well as the radiation and convection from the surface, any errors of determination of the other items. In particular, the uncertainty of the blow-out gas temperature will affect the radiation considerably; too high an estimate will result in too low a radiation loss and *vice versa*.

The heat loss from the brickwork has also been calculated from a combination of measured inside and outside temperatures and estimated inside temperatures. This is seen to be 2·68 million B.Th.U./hr., compared with the average difference value of 4·94 million B.Th.U./hr. The blow-out loss may therefore have been under-estimated, but this cannot be stated with any confidence, since the calculation of furnace structure losses is itself only approximate, as several assumptions were made. In addition, the errors of other determinations in addition to those of blow-out loss are included in the difference figure.

Characteristic Curves

Table V shows that the average efficiency of the furnace plus recuperator was 53·4%; one test was as low as 44·7% and one as high as 61·5%, the remainder of the trials gave values between 50% and 55%. In view of the limitations imposed on the furnace by burner port design, inadequate air supply, and a faulty recuperator, these efficiencies are very creditable, and very little improvement could be effected in the operation of the furnace in its present condition. The furnace-pressure controller fitted for the trials will, of course, have helped in obtaining these good results.

The figures in Table V have also been plotted as percentages of heat input against heat input for the furnace only and for the furnace with the recuperator. The curves are similar in shape in both cases, and Fig. 27 shows those for the furnace and recuperator.

A furnace tested under similar conditions but at different loads would be expected to produce a certain

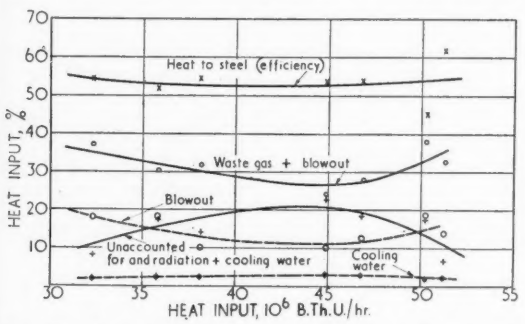


Fig. 27—Characteristic curves of furnace and recuperator

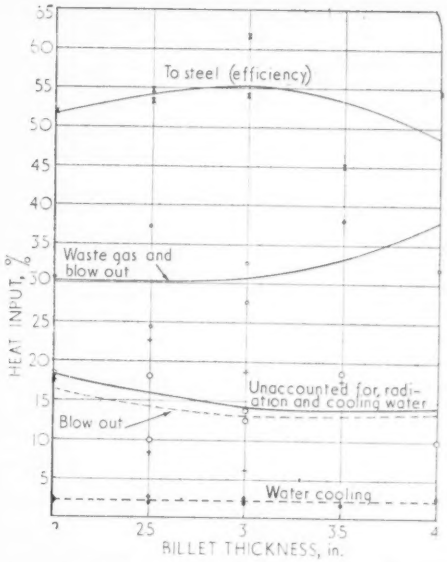


Fig. 28—Effect of billet size on heat balance

form of characteristic curve. The radiation loss would be expected to remain approximately constant in amount (*i.e.*, it would steadily fall when expressed as a percentage) and the waste-gas and blow-out loss may be expected to remain constant (constant waste-gas temperature), possibly rising at higher heat inputs as the waste-gas temperature increases. The effect of these two factors would result in the efficiency rising with output, possibly reaching a maximum and falling again.

Examination of Fig. 27 shows none of these effects. The best line drawn for heat to steel or efficiency is almost constant, with a possible minimum. The 'waste gas + blow-out' curve shows a minimum followed by an increase, and the radiation loss as given by difference first rises with increased heat input and then falls again. The blow-out and cooling-water losses are plotted separately and are shown as broken lines, and it will be evident that the heat in the waste gas passing to the recuperator will be almost constant and that the almost constant water-cooling loss would have little effect on the shape of the radiation curve.

It is, of course, difficult to draw conclusions from lines drawn from only seven points, and whether a curve passing close to the points is justified is perhaps doubtful. The data on which Fig. 27 was constructed differ from the ideal case quoted in that the brickwork losses do not remain constant, but tend to rise with heat input (*see* Fig. 26). The waste-gas temperature also rises with increased heat input, both these results tending to give a flat efficiency curve. One of the main reasons for the differences between the curves in Fig. 27 and the expected type of characteristic is that the tests were not under similar conditions, as different billet sizes were heated, and it is thought that the curves would more nearly follow the expected shape if the furnace had been tested at a variety of loads on one billet size. Reference to Fig. 12 shows why the efficiency is almost constant; the heat-to-

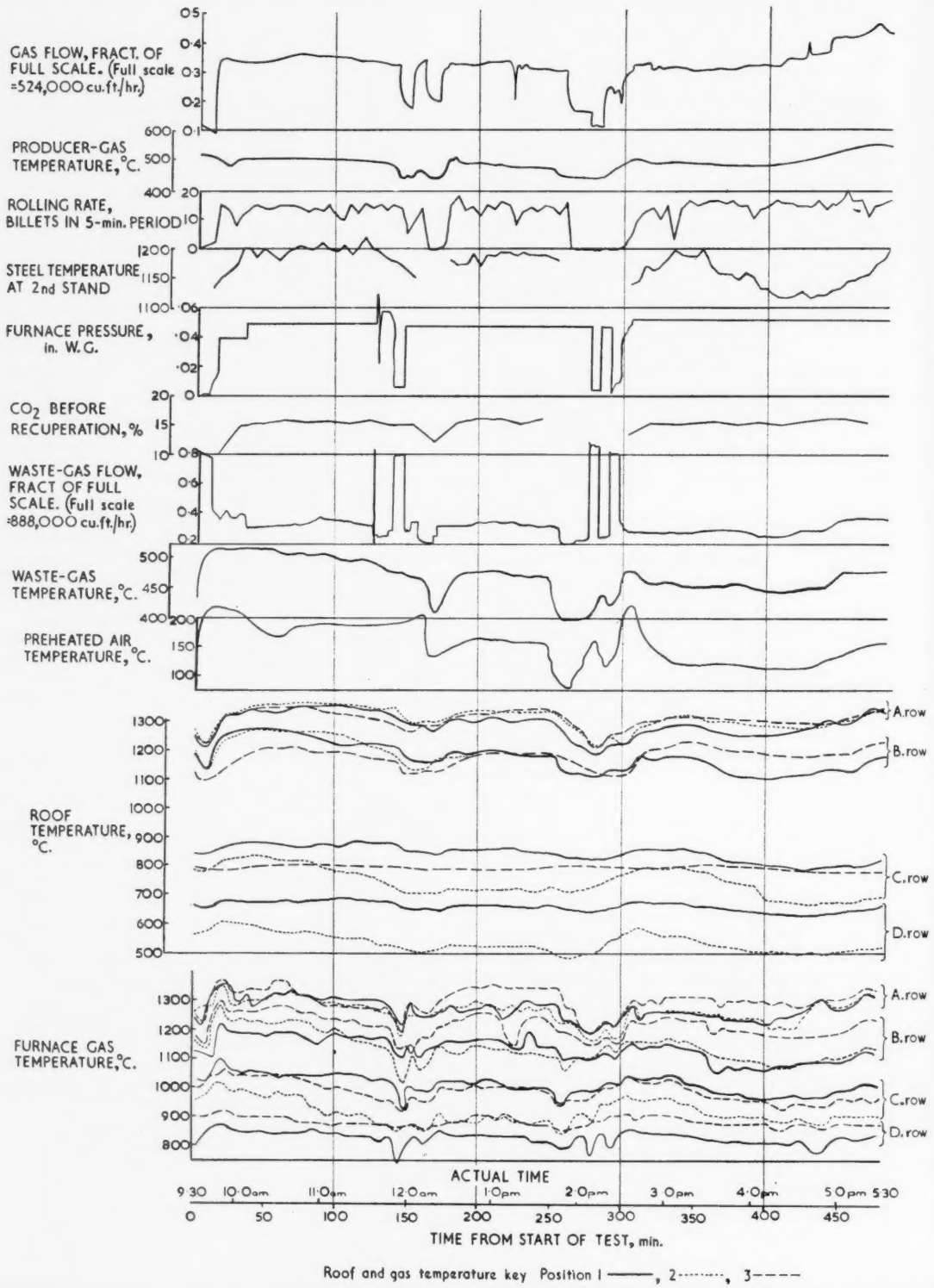

GAS FLOW, FRACT. OF FULL SCALE. (Full scale =524,000 cu.ft./hr.)
PRODUCER-GAS TEMPERATURE, °C.
ROLLING RATE, BILLETS IN 5-min. PERIOD
STEEL TEMPERATURE AT 2nd STAND
FURNACE PRESSURE, in. W.G.
CO_2 BEFORE RECUPERATION, %
WASTE-GAS FLOW, FRACT OF FULL SCALE. (Full scale =888,000 cu.ft./hr.)
WASTE-GAS TEMPERATURE, °C.
PREHEATED AIR TEMPERATURE, °C.
ROOF TEMPERATURE, °C.
A.row
B.row
C.row
D.row
FURNACE GAS TEMPERATURE, °C.
ACTUAL TIME
9·30 10·0am 11·0am 12·0am 1·0pm 2·0pm 3·0pm 4·0pm 5·0pm 5·30
0 50 100 150 200 250 300 350 400 450
TIME FROM START OF TEST, min.
Roof and gas temperature key Position 1 ——, 2·····, 3– – –

Fig. 29—Master chart of main variables (test 1)

steel/heat-input curve passes almost through the origin. The shapes of the 'waste gas + blow-out' and the radiation-loss curves are thus functions of both billet size and output. Alternatively, the structural losses may be considered, together with the blow-out losses, to be almost constant. These are the two most difficult items to determine, and it may well be that it is merely an overestimated blow-out loss that causes a low structural loss (by difference). Then Fig. 27 can be considered to show all the losses to be almost constant (as a percentage of heat input); thus, it may be the increase in the hourly rates of heat loss through blow-out and structural losses that results in the almost constant furnace efficiency.

In Fig. 28 the same factors are plotted against billet size, and although a close correlation would not be expected, as the load was at different levels during the tests, it does illustrate some interesting points. The best line for efficiency shows an indication of approaching a maximum with 3-in. billets and falling off with larger or smaller ones. The 'waste gas + blow-out' losses are at first constant and then rise on the larger billet sizes, owing to an increase in the waste-gas temperature. The radiation curve decreases up to 3-in. billets and then remains constant, the blow-out loss following a similar sort of curve. A low efficiency on the smaller sizes is apparently due to the radiation loss being high when expressed as a percentage of the relatively low heat input. Up to 3-in. billets, the percentage radiation decreases owing to the higher input and, since the waste-gas and blow-out loss remains steady, the efficiency rises. On the larger billets, however, the waste-gas loss increases owing to higher waste-gas temperatures, and the radiation remains constant, resulting in a decreased efficiency. It is apparent that some such effect is present, as it has been noted both from the test results and from statistical analysis that with similar gas rates the rate of output with larger billets is lower.

Figures 27 and 28 obviously do not tell the whole story: in the former the effect of billet size is omitted and in the latter the effect of output; nor is there sufficient evidence to prove the noted trends. Complete characteristic curves should show the effect of load on each billet size, with possibly the influence of furnace-pressure variation included.

ROOF AND GAS TEMPERATURE IN FURNACE CHAMBER

It is necessary to have a complete picture of the temperatures existing inside the furnace to investigate the efficiency of combustion, temperature gradients, and heat transfer. The gas and roof temperatures were measured during the seven short-period trials at 12 points in the furnace, as previously described.

The temperatures from each test were tabulated, the roof-temperature readings being taken for similar time intervals as the combustion-gas temperatures. The results were averaged between tests, between rows, between columns, between depths, and between individual points. Some of the results are given in Table VI.

A typical plot on a time base of the temperatures and the other main variables for one of the tests is given in Fig. 29. This shows how closely the temperatures in the different parts of the furnace follow each other and that the periods of low temperatures correspond to periods of low CO_2 (*i.e.*, when furnace pressure or gas flow are low), showing that air/gas ratio and infiltrated air markedly affect the furnace temperature. The effect of the mill stoppage at 1.45 p.m. is of interest. When this occurred, the gas flow was reduced and all the temperatures decreased for a time but although the temperature of the roof and gas at the hot end of the furnace continued to drop throughout the stoppage, the temperature at the charge end of the gas (and of the roof to a lesser degree) gradually rose, so that the temperature

Table VI
AVERAGE GAS AND ROOF TEMPERATURES

Test No.*	A Row			B Row			C Row			D Row			Average
	1 (S)	3 (L)	5 (M)	1 (L)	3 (M)	5 (S)	1 (M)	3 (S)	5 (L)	1 (L)	3 (M)	5 (S)	
(*a*) ***Gas Temperatures***, ° *C.*													
1	1270	1255	1295	1135	1140	1215	1005	915	990	835	...	885	1067
2	1375	1385	1400	1245	1220	...	1020	970	1000	860	855	850	1118
3	...	1480	1460	1170	1185	1240	1040	970	1060	815	835	900	1135
4	1495	1475	1525	1250	1230	1255	1060	990	970	865	905	905	1160
5	1410	1520	1475	1265	1260	1300	1020	1030	1010	845	...	900	1159
6	1370	1260	1330	1175	1210	1200	1020	965	980	825	835	870	1087
7	1295	1275	1375	1110	1235	1215	980	960	...	785	825	840	1072
Average	1369	1379	1409	1193	1211	1238	1021	971	1002	833	851	879	1114
(*b*) ***Roof Temperatures***, ° *C.*													
1	1285	1310	1300	1155	1210	1170	845	745	795	665	540	...	969
2	1360	1340	1355	1225	1200	1250	920	775	890	710	630	690	1029
3	1210	1320	1330	1175	1205	1250	810	820	955	610	630	745	1005
4	1300	1390	1350	1210	1180	1270	970	810	925	740	...	705	1048
5	1305	1450	1370	1190	1165	1310	895	855	940	700	685	695	1047
6	1320	1350	1350	1210	1165	1215	885	835	930	690	620	780	1029
7	1300	1365	1380	1180	1175	1280	840	815	895	620	580	705	1011
Average	1297	1361	1348	1192	1186	1249	881	808	904	676	614	720	1020

* Letters in parentheses refer to length of thermocouple sheath for gas temperature measurements: S = short, M = medium, L = long

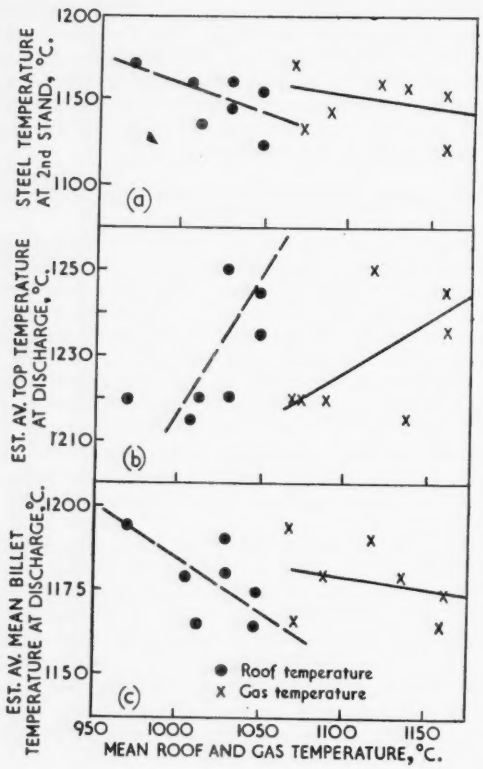


Fig. 30—Effect of furnace temperature on steel temperature

difference throughout the length of the furnace was reduced. This was, of course, because no steel was being charged to absorb the heat. Another contributory factor was that the roof cooling-water flow (at the hot end) increased when the mill stopped and its water supply was cut off, thus tending to increase the cooling rate of the roof at the hot end.

Overall Temperature Level

The overall temperature level, as defined by the mean of the roof and gas temperatures at the twelve measuring stations in the furnace chamber, was examined to determine on what factors it depends. It was found that increases in gas flow, steel output, and waste-gas flow are accompanied by increased average furnace temperatures.

The effect of the furnace temperature on steel temperature is illustrated in Fig. 30. This shows that the average top temperature of the steel at discharge increases with roof and gas temperature. This is as expected, but the estimated mean temperature of the billets and the top temperature at the second stand in the mill go down with increasing average temperature in the furnace.

This means that an increased furnace temperature results in a higher 'skin' temperature but a lower bottom temperature, and this is reflected in the temperatures in the mill where the 'skin' has cooled. This is because the higher furnace temperatures correspond to periods when high outputs of large billets are desired. Shortage of time and thick billets prevent good temperature equalization, the mean temperature being actually reduced.

It follows that, with the existing furnace design, variables causing the average furnace temperature to rise will give inferior soaking. The implications are

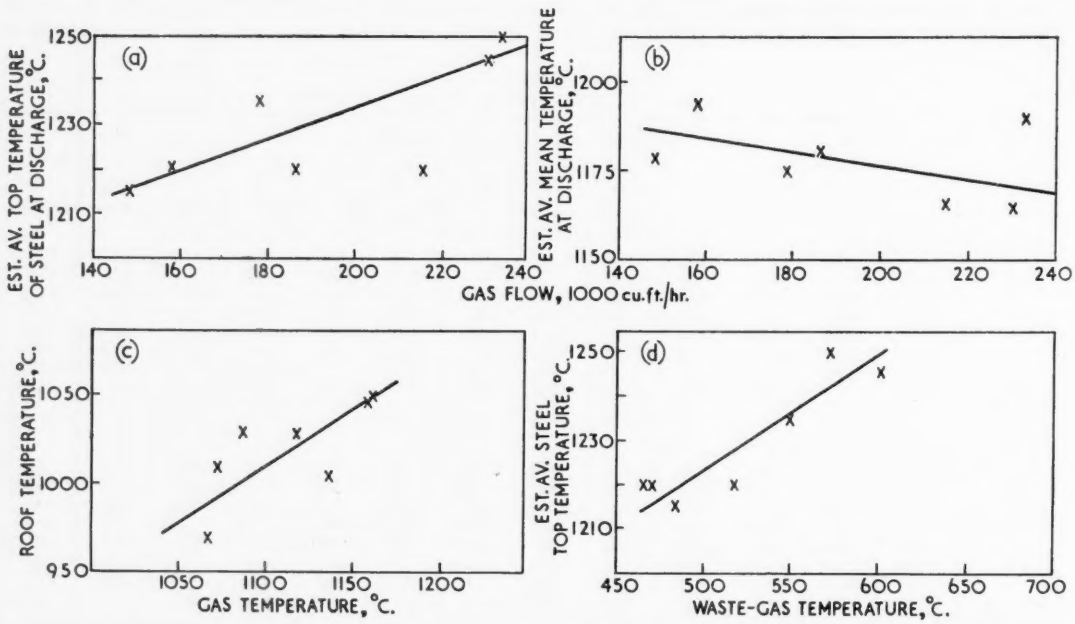


Fig. 31—Relationships between gas flow and steel, waste-gas, and furnace temperatures

more easily grasped by considering Figs. 31*a* and *b*, where the top temperature and the mean temperature of the steel at discharge are plotted against producer-gas flow. The mean temperature is seen to decrease, although the top temperature rises, as more producer gas is burnt. Figure 31*d* shows that the steel-top temperature at discharge is more closely related to the waste-gas temperature before the recuperator than to the furnace temperature. This demonstrates that the waste-gas temperature gives a good measure of the conditions inside the furnace chamber. The average roof and gas temperatures are related, as shown in Fig. 31*c*. This is to be expected from the similarity of their correlations with other factors.

Average Distribution Pattern

The average pattern constructed for the whole of the seven tests is given in Fig. 32. The averages along the length, width, and height of the furnace are plotted in Fig. 33. These show that the average gas temperature falls almost linearly with distance from the hotter end. The roof temperature falls slowly at the hot end, more quickly in the middle zones between *B* and *C* rows, and more slowly again at the back of the furnace. The sides of the furnace are generally hotter than the middle. This is because the billets do not extend the full width of the furnace and thus have less heat-absorption capacity at the side. At the hot end of the furnace, however, the sides are cooler than in the middle (*see* Fig. 32), owing to air infiltration through the discharge doors, and reduced gas flow near the doors. (It is considered that the gas temperature at *A* row would have exhibited a similar effect had the long couple, which generally gives the lowest reading, not been in the centre of the furnace.) The side-to-side uniformity is worse at the back of the furnace. The average side-to-side uniformity was better when the furnace temperatures were high, perhaps owing to the higher gas velocities obtaining.

The temperature fluctuations tend to decrease from the hot end to the cold, so that a change in temperature at the hot end results in a change of smaller magnitude

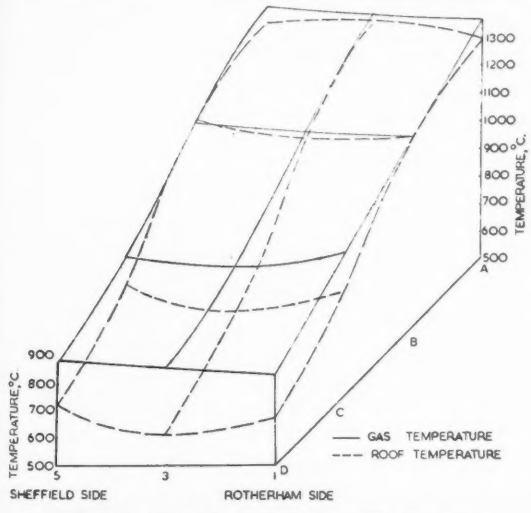


Fig. 32—Average temperature distribution

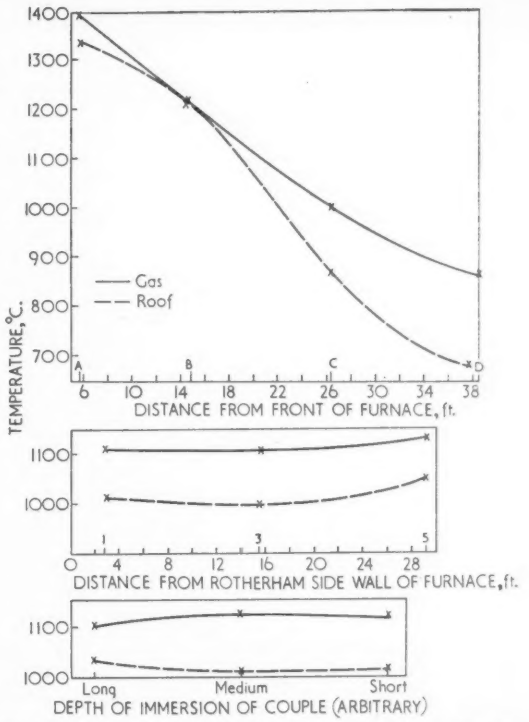
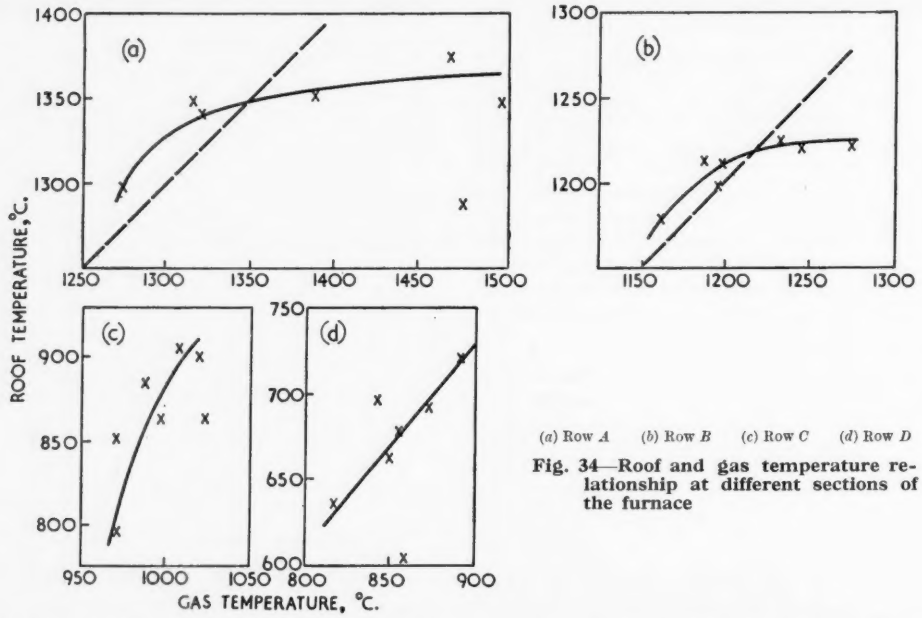


Fig. 33—Average roof and gas temperature distribution (all tests)

at the back of the furnace. The random fluctuations of gas temperature were more marked than those of roof temperature, owing to the heat capacity of the roof brickwork.

Figure 33 shows that there is evidence that long couples give lower readings (about 40° C.) than the others owing to air infiltration. There is also a tendency for the short couples to read slightly lower than the medium ones, but this is probably not significant. There is a weakness in using such averages, because each column averages two points with couples in the same length group and *vice versa*. This could have been obviated by the adoption of a $4 \times 4 \times 4$ or $3 \times 3 \times 3$ plan (*i.e.*, the same number of rows, columns, and heights). In future work this would be done and the position of the various length couples would be changed in a random fashion before each test.

Figure 33 shows that the roof-temperature curve lies very close to the gas-temperature curve at *B* row. Similar figures plotted for each test showed that in four of the seven tests the average roof temperatures at *B* row, and sometimes at *A* row, were higher than the corresponding average gas temperature. This is difficult to explain, but it was noticed that it occurred on the lower-load tests. The effect of some of the variables on the difference between gas and roof temperature was examined, and it was found that the difference is more positive (positive when the gas is hotter than the roof) when the average roof and gas temperatures are higher, *i.e.*, with higher gas flows and thicker billets. It appears that the short flames, low gas rates,



(*a*) Row *A* (*b*) Row *B* (*c*) Row *C* (*d*) Row *D*

Fig. 34—Roof and gas temperature relationship at different sections of the furnace

and high air/gas ratios at the ports associated with thinner billets cause the roof to get hotter than the average gas temperature. Possible explanations are as follows. The gas temperature is the average of readings at three different levels, and if very short couples had been used the anomalies would be less obvious. The flame is projected against the roof and burns under the roof in a layer whose thickness is determined by gas rate and furnace pressure. At lower flows the layer tends to be thinner, and it is possible for there to be a severe temperature gradient through the gas which gives the maximum temperature in a thin layer of flame under the roof, so that the roof temperature is higher than the average temperature in the body of the furnace where the gas couples are situated. The possibility of surface combustion at the roof surface should also not be ruled out.

Relation between Gas and Roof Temperatures in Different Parts of Furnace

Whereas the gas temperature varied from test to test more at the front of the furnace, the roof temperature varied more at the back. This is shown by

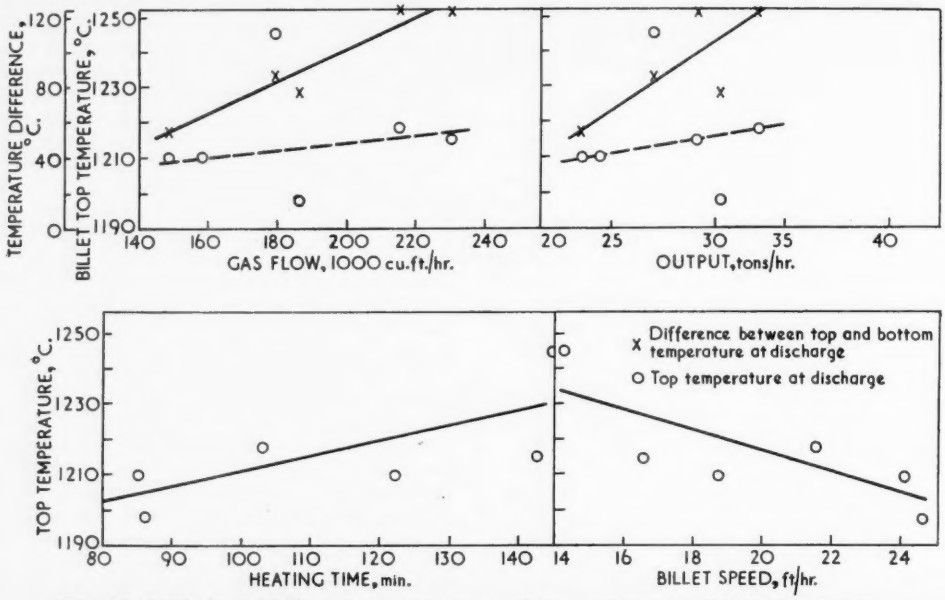

TEMPERATURE DIFFERENCE, °C.
BILLET TOP TEMPERATURE, °C.
GAS FLOW, 1000 cu.ft./hr.
OUTPUT, tons/hr.
TOP TEMPERATURE, °C.
HEATING TIME, min.
BILLET SPEED, ft/hr.
x Difference between top and bottom temperature at discharge
o Top temperature at discharge

Fig. 35—Variation of billet-top temperature and temperature gradient at discharge

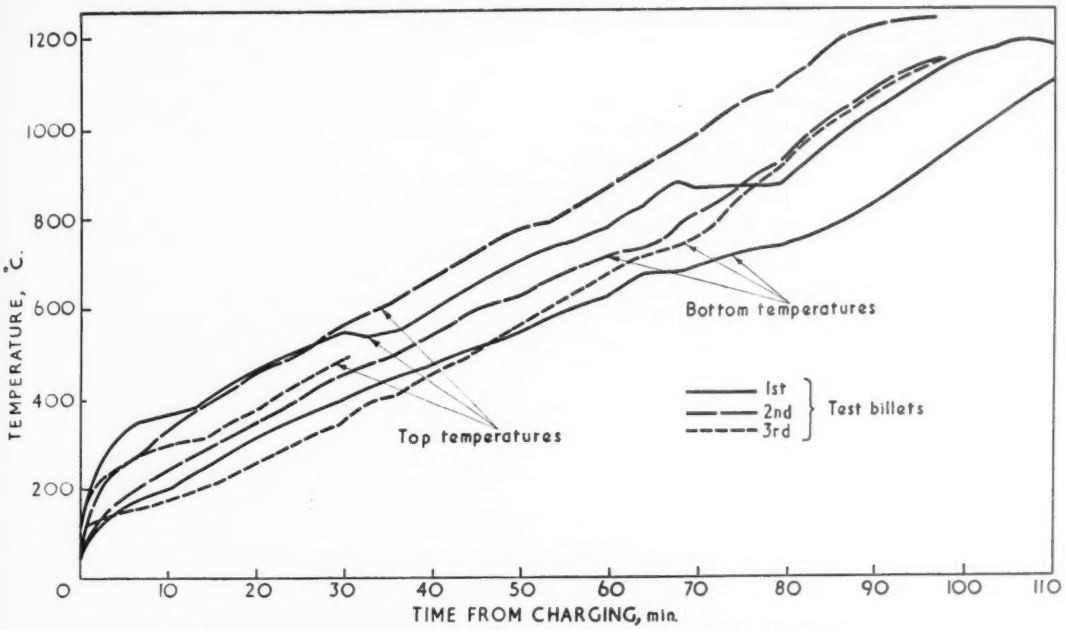


Fig. 36—Steel-temperature/time relationship: test 7 (3-in. billet)

Fig. 34: in the *A* and *B* rows the roof temperature appears to approach a maximum with increasing gas temperature at about 1350° and 1225° C., respectively. This is probably due to the suppression of the roof-temperature rise by the cooling water in these two sections and explains the small variation of the roof temperature in these sections.

STEEL TEMPERATURE VARIATIONS

Discharge Temperature of Billets

The average steel temperatures at discharge for each test have already been discussed in relation to furnace temperature, and it was shown that high average gas temperature and large end-to-end temperature gradients give high steel-top temperatures but poor soaking. (It was also discovered that better soaking is obtained by using high furnace pressure and relatively low air/gas ratios.)

The average top temperature at discharge and the top-to-bottom temperature differences are plotted against some of the variables in Fig. 35. This diagram confirms the previous findings from the study of average temperature, that an increase in gas flow and output rate gives inferior soaking. In addition, a a quantitative measure is given of what is meant by bad soaking, as the bottom temperature can be as

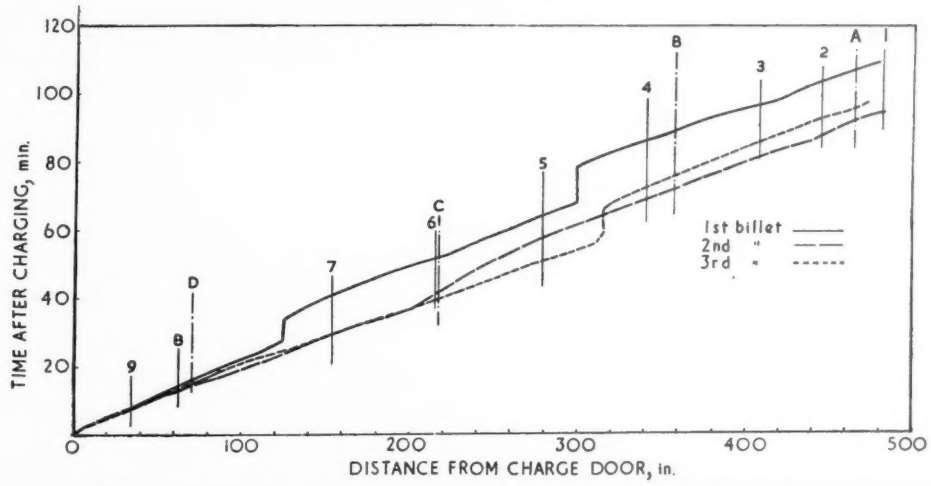


Fig. 37—Rate of pushing (test 7). Figures refer to door positions, letters to row positions

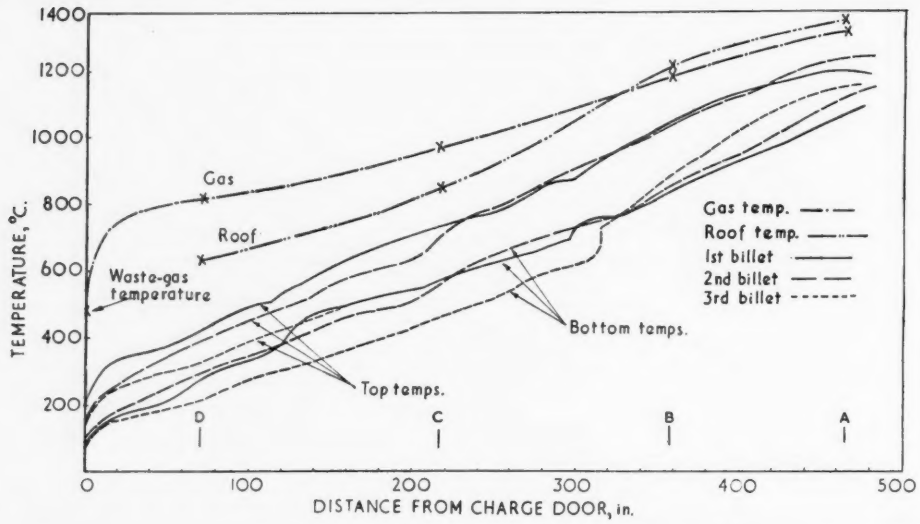


Fig. 38—Temperature/position relationships (test 7), together with gas and roof temperatures. Letters refer to row positions

much as 120° C. below that of the top surface. It is also shown that there is a tendency to have higher top temperatures when the heating time is greater and the speed of travel is slower.

It was also found that steel-top temperature tended to increase with higher roof and gas temperatures, higher air/gas ratios, and lower furnace pressure. The temperature difference or degree of soaking did not, however, show a very good correlation with any of these factors.

Heating Curves of Test Billets

Heating curves have been prepared for all test billets and Figs. 36, 37, and 38 are a typical set of curves showing the temperature/time, time/distance, and temperature/distance relationships. These refer to test 7, heating 3-in. billets, and, apart from showing the relative top and bottom temperatures, are of interest in showing the effect of stoppages. The second test billet was heated most rapidly and was pushed through without a stoppage, although a slight slowing-down occurred after the billet had travelled 200 in. This is reflected by a hump in the temperature/distance curve. The slowing-down was not accompanied by a reduction in gas rate, so the time/temperature curve is smooth. In contrast, the two stoppages which occurred whilst heating the first test billet were accompanied by a reduction in gas rate, and the top

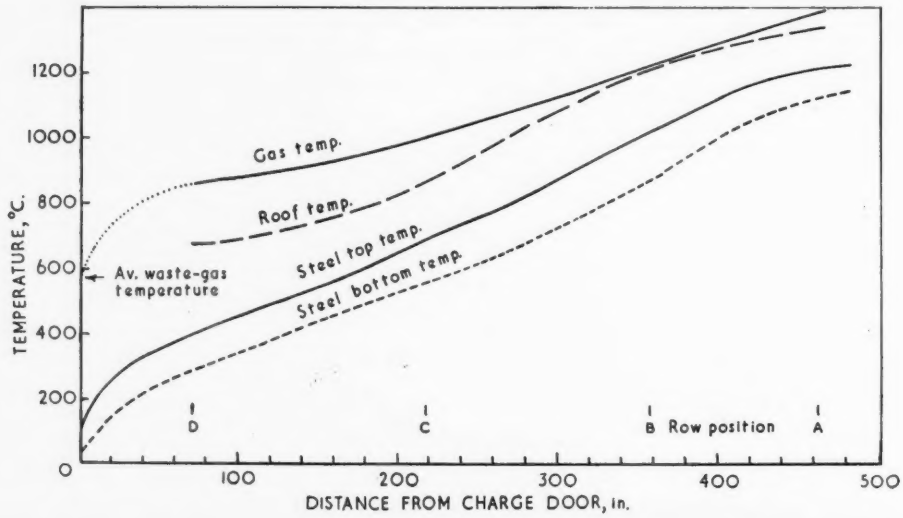


Fig. 39—Average gas, roof, and billet temperatures for all tests

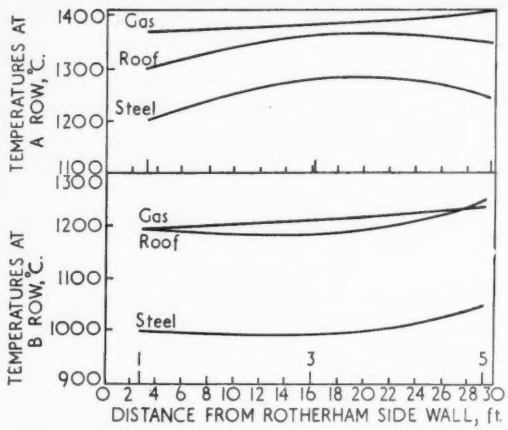


Fig. 40—Gas, roof, and steel temperatures across the furnace; average for all tests

temperature in each case ceased to increase with time. This results in the temperature/distance curve being unaffected by the stoppages. This is what normally occurs, but the billet bottom temperature continues to rise, giving improved soaking. On occasions when the gas is left on, the top temperature can also rise.

From a study of all the time/top-temperature curves obtained in the trials, it was observed that a heating time of 100 min. can be attained on all billet sizes. This does not mean, of course, that this time would give adequate soaking with the thicker billets. A considerable variation in top temperature with time is also found, but the variation in temperature at a given position in the furnace is much less, the spread decreasing as the discharge end is approached. It was also confirmed that thicker billets have a higher final top temperature.

The average top and bottom temperatures for all the successful billet tests, together with average furnace temperatures, are plotted against distance in Fig. 39. The curve for steel temperature shows a marked depression or decrease in the rate of temperature rise in the middle zones of the furnace instead of decreasing steadily towards the hot zone. The latter is the form of curve known to give the best temperature equalization of the stock. The roof-temperature distribution is similar to the steel-top temperature, and the gas temperature also exhibits such tendencies, although the temperature head above steel temperature increases towards the colder zones. Attempts to define the factors affecting the changes of steel top temperature in the various parts of the furnace were rather inconclusive, although there was evidence that greater furnace temperatures, gas rates, and billet sizes cause the steel temperature to rise at the hot end of the furnace (rows *A* and *B*). There was also slight evidence that thicker billets resulted in lower cold-end temperatures.

Side-to-Side Temperature Distribution

The only available measure of side-to-side temperature differences across the billet are the optical readings taken through tubes at the hot end of the furnace. Table VII summarizes the results.

Figure 40 shows that the side-to-side uniformity is not very good, as the average temperature difference along the billets is 80° C. The ends are hotter than the middle at *B* row, but are colder at discharge (*A* row), owing to air infiltration through the discharge doors. Similar curves are exhibited by the roof and the steel temperatures. Since this effect can also be seen in Fig. 39 for the end-to-end distribution, it can be concluded that roof and steel temperatures are strongly interrelated.

Temperature Distribution within the Steel

The temperature distribution throughout a billet was required, so that the amount of heat it contained at any given time could be assessed, and thereby the net rate of heat transfer from the flame to the billet.

The temperature distributions were obtained by using an electrical heat-flow computer.[3] The method used was to construct the time/temperature curves at points a quarter, a half, and three-quarters of the billet thickness which, together with the measured

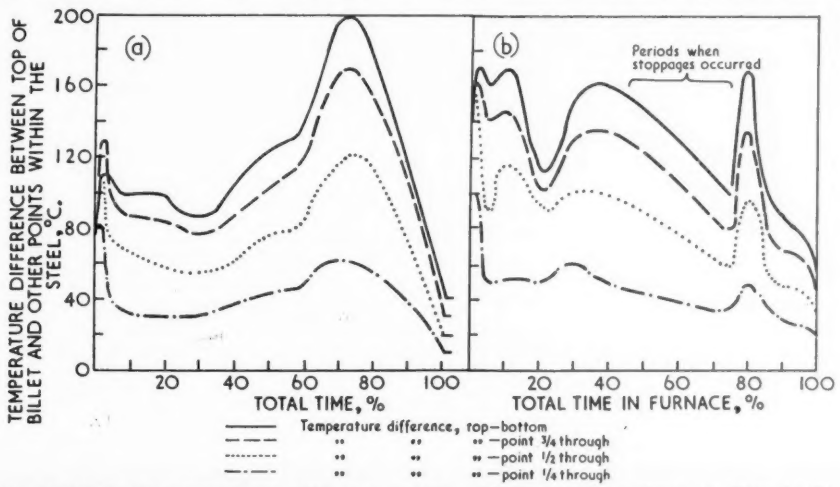


Fig. 41—Variation of temperature difference within a billet, based on time: (*a*) Test 6; (*b*) test 5

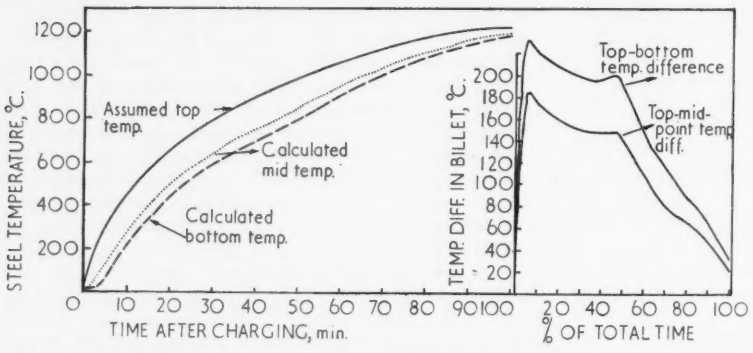


Fig. 42—(*a*) Idealized heating curves and (*b*) temperature-difference curves for a 4-in. billet

top and bottom temperatures, enabled temperature/depth curves to be plotted at any instant. From these the heat content at any time can be derived purely from the thermal capacity. It should also be possible, by using the tangents of these curves at the upper and lower surfaces, to determine the instantaneous heat flow into the steel and from the steel to the hearth. An estimate was made of the effect of small errors in the top and bottom temperatures, such as could be caused by scale layers on the steel, and it was shown that they could cause very large variations in calculated heat transfer when using the temperature gradient, although the heat-capacity method is not greatly affected. The latter method is thus used in calculating net heat flow to the steel.

The temperature distribution occurring within the billets is illustrated by Fig. 41*a*, which is typical of nearly all other tests, except those disturbed by stoppages. The temperature differences within the billets increase rapidly at first after charging and then fall to a minimum when the top temperature is 400–600° C. (20–30% of total heating time). The differences then rise to a maximum when the top temperature is about 1000° C. (70–80% of the total heating time), finally falling again to the discharge point. The curve in Fig. 41*b* clearly shows the effect of stoppages.

It is interesting to consider the ideal shape for these curves to give the most rapid heating consistent with good soaking. Since it is desirable to heat thicker sections much more quickly than at present, an example has been chosen of a 4-in. billet being heated in 100 min. The top-temperature/time curve in Fig. 42 has been partly derived from Fig. 39 (average top-temperature/distance curve), but it has been arbitrarily improved by eliminating the concave section in the middle and increasing the initial temperature rise to represent something that might be possible with two-zone heating. To calculate the internal and bottom temperatures, the method of Hulse, Price, and Sarjant[4] has been used. This method enables the effects of variable diffusivity to be included and assumes no heat loss from the bottom of the billets. The result of changing the top temperature curve on the temperature difference within the billet is most marked. The maximum temperature difference is at about 5% of the total heating time and the difference falls steadily after 50% of the total time. The shape of the curves before 50% of the total time is due to the influence of the change point, which tends to increase the temperature differences. That the variable diffusivity is responsible for the peculiarities of Fig. 42 was confirmed by making a similar calculation, but assuming constant diffusivity.

The temperature difference at discharge is only 32° C. (this will be slightly low, owing to the assumption of no heat loss to the hearth) and the rate of heating assumed can give good soaking if the temperature/time curves can be modified appropriately. The present firing system gives inferior performance, as shown by Fig. 43, where maximum and final temperature differences per inch of thickness are plotted against heating time per inch of thickness. According to these curves (extrapolated), any attempt to heat 4-in. billets in 100 min. would result in a maximum temperature difference of about 350° C. at 70–80 min. after charging and a final temperature difference of about 140° C. The improvements possible by adjustment of the heating curve are very evident.

In regard to the cause of changes in the internal

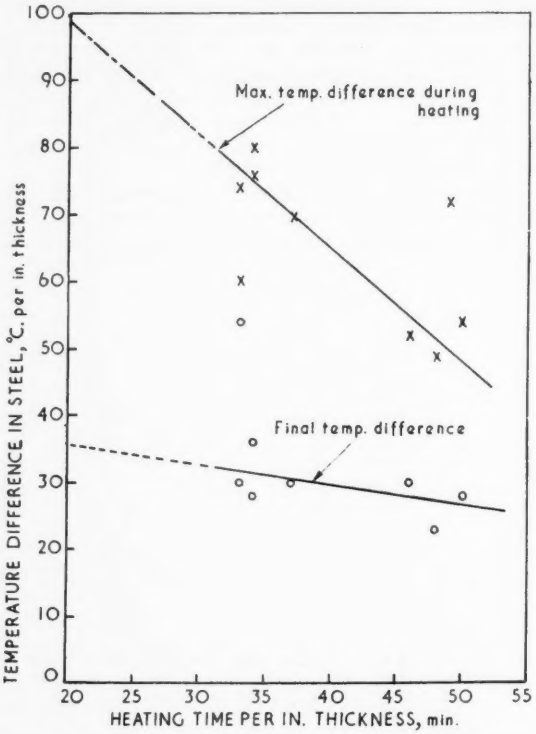


Fig. 43—Relationship between temperature equalization and heating time

Table VII

AVERAGE STEEL TEMPERATURES BY OPTICAL PYROMETER, ° C.

Test No.	Billet Size, in.	*A*1	*A*3	*A*5	*A* Row (Av.)	*B*1	*B*3	*B*5	*B* Row (Av.)
1	2	—	—	—	—	999	947	1132	1026
2	3	1140	1228	1143	1170	970	952	973	965
3	2½	1187	1277	1242	1235	1003	1009	1070	1027
4	4	1194	1254	1196	1215	1097	1057	1043	1066
5	3½	1240	1287	1279	1269	1005	1040	1063	1036
6	2½	1238	1278	1268	1261	974	962	1057	998
7	3	1196	1335	1343	1291	958	989	1029	992
Average		1199	1277	1245	1240	1001	994	1052	1016

Table VIII

OVERALL HEAT TRANSFER TO STEEL

Test No.	1	2	3	4	5	6	7
Billet Size, in.	2	3	2½	3½	4	2½	3
Heat-transfer area, sq. ft.	1068	1102	1053	1034	1120	1066	1120
Heat transfer, 10^6 B.Th.U./hr.	18·55	31·49	17·55	20·64	22·47	23·80	25·15
Heat transfer, 10^3 B.Th.U./sq.ft. hr.	17·38	28·60	16·67	19·97	20·08	22·34	22·45
Av. steel temp. (test couples), ° C.	742	—	739	—	790	706	770
Av. roof temp., ° C.	908	948	943	982	979	965	938
Av. gas temp., ° C.	1025	1059	1048	1092	1096	1032	1020
Heat transfer based on av. gas – steel temp. difference, B.Th.U./sq.ft. hr. ° F.	34·1	—	30·0	—	36·5	37·0	49·9
Heat transfer based on av. roof – steel temp. difference, B.Th.U./sq.ft. hr. ° F.	58·2	—	45·4	—	59·1	47·9	84·3

temperature distribution, it has already been shown (Fig. 43) that the heating rate per inch has a marked effect, longer heating times giving improved curves. Examination of the effect of other factors shows that

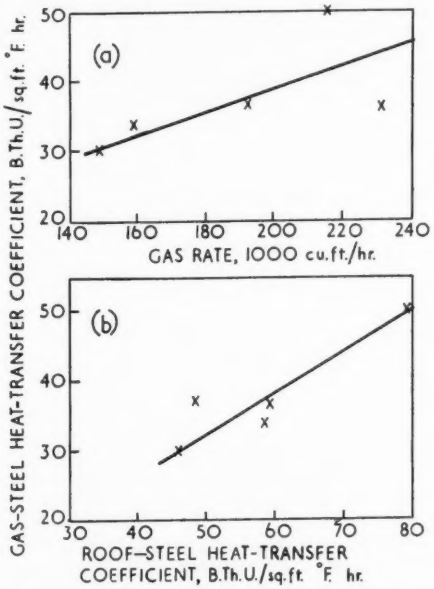


Fig. 44—Overall heat-transfer coefficients (based on mean gas, roof, and steel temperatures)

billet thickness has the expected effect of increasing the temperature difference, the temperature difference per inch, however, being virtually unaffected. The latter is reduced when the actual heating time is larger. With the furnace as at present designed, it appears that the only way of improving the soaking is by longer heating times, with resultant lower outputs. As high outputs are required, the steel-top-temperature/time curve must be modified by the addition of more heat further back in the furnace, as would be possible with two-zone heating.

HEAT TRANSFER TO STEEL

Overall Rates of Transfer

The overall coefficients of heat transfer (in B.Th.U./sq.ft. hr. ° F.) based on average temperatures and the surface area of the raft of billets (the product of the distance between centre-lines of charge and discharge doors and the average billet length) are given in Table VIII, together with the data on which they are based.

Mean temperatures have been used, as the use of terminal temperatures with log mean temperature differences is considered to be inapplicable to a furnace where there is delayed combustion of the fuel and most of the heat is transferred by radiation. The use of mean temperature has, however, the disadvantage that the average billet-top temperature is only known for the test billets, and this may not necessarily be representative of all billets. The terminal conditions for the gas and roof are also not known and the

Table IX

HEAT TRANSFER BASED ON FOURTH-POWER TEMPERATURE DIFFERENCES

Test No.	1	2	3	4	5	6	7
Calculated flame temp., ° C.	1610	1590	1390	1590	1680	1570	1680
Gas temp. at *A* row, ° C.	1270	1390	1370	1500	1485	1330	1330
Pyrometric efficiency ratio	0·79	0·88	0·98	0·95	0·89	0·85	0·79
Waste-gas temp., ° C.	470	570	490	550	600	520	470
Steel temp. at discharge, ° C.	1220	1250	1215	1235	1245	1220	1220
Steel temp. at charge, ° C.	15	13	13	6	8	16	22
$(T_F^4 - T_S^4)$ av. $\times 10^{-12}$ (using calculated flame temp.)	15·83	19·12	10·08	18·50	24·20	16·80	17·77
$(T_F^4 - T_S^4)'$ av. $\times 10^{-12}$ (using *A* row temp.)	4·80	11·17	9·35	15·36	16·40	8·34	7·32
Heat transfer, B.Th.U./sq. ft. hr. $\times 10^{-3}$	17·38	28·60	16·67	19·97	20·08	22·34	22·45
α in $q = \alpha A (T_F^4 - T_S^4)$ (calculated flame temp.) $\times 10^9$	1·098	1·496	1·654	1·080	0·831	1·330	1·264
α' (using *A* row temp.) $\times 10^9$	3·62	2·56	1·78	1·30	1·23	2·68	3·07
Continuity ratio	0·761	0·929	0·925	0·778	0·702	0·875	0·784

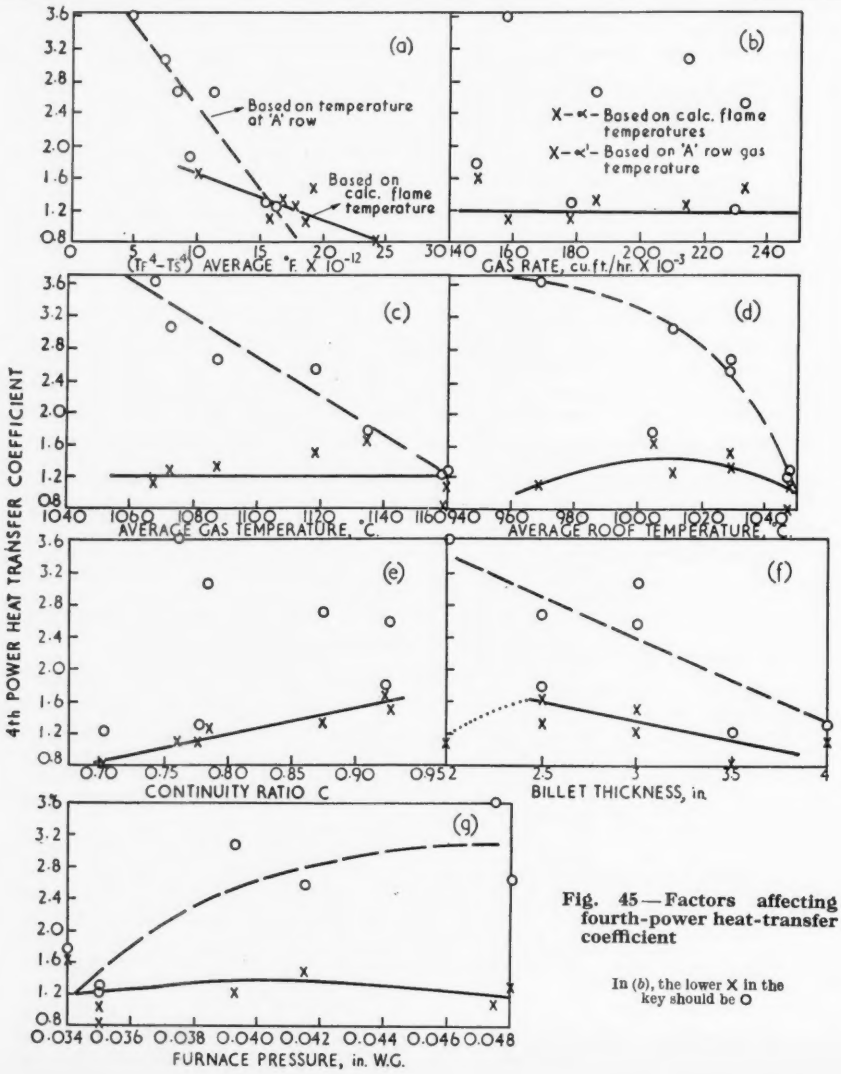


Fig. 45—Factors affecting fourth-power heat-transfer coefficient

In (*b*), the lower X in the key should be O

curves have to be extrapolated, although this should not give rise to any serious error.

The reasons for the changes in the heat-transfer coefficients shown in Table VIII have been investigated by plotting them against other variables, and the only reasonable relationship found (*see* Fig. 44*a*) was with producer-gas flow rate, higher gas rates resulting in a higher heat-transfer coefficient. The gas–steel and roof–steel coefficients were also found to be related, as shown by Fig. 44*b*.

It is well known, however, that heat transfer in a reheating furnace is mainly by radiation, which depends on the fourth-power temperature difference. An equation of the form

$$q = \alpha A (T_F^4 - T_S^4)$$

should thus be applied, where α is a coefficient, A is the heat-receiving area, and T_F and T_S are the absolute flame or gas temperature and the steel temperature, respectively. Eberhardt and Hottel[5] developed an equation for heat transfer in reheating furnaces of the form

$$q_1 = P_s P_f' A' \sigma (T_F^4 - T_S^4)$$

where P_s is the steel emissivity, P_f' is a pseudo gas emissivity incorporating the convection transfer, A' is an equivalent area calculated to take into account the effects of re-radiation from refractories, and σ is the radiation constant. Thus

$$\alpha = P_s P_f' \frac{A'}{A} \sigma.$$

The value of α can be obtained if the average fourth-power temperature difference can be calculated, and Eberhardt and Hottel use the terminal temperatures in an approximation

$$(T_F^4 - T_S^4)\text{Av.} = \sqrt{[(T_{F(1)}^4 - T_{S(1)}^4)(T_{F(2)}^4 - T_{S(2)}^4)]}.$$

The latter temperature difference has been calculated using the A-row gas temperature and the calculated flame temperature as the hot-end gas temperatures, thus enabling values of α to be determined. The designations α' and α have been used for the coefficients derived from the A row and the calculated flame temperatures, respectively.

Table IX shows the temperatures, the fourth-power temperature differences, and the values of the coefficient. The pyrometric efficiency quoted in Table IX is the ratio of the measured gas temperature at A row and the calculated flame temperature, which varies from 0·79 to 0·98. The exceptionally high value occurred when combustion was effected with a large amount of excess air, thus giving rapid combustion and a low theoretical flame temperature. The pyrometric efficiency is shown to depend very largely on the amount of excess air used; it is lower as the excess air is reduced. This effect has also been noted by Hammond and Sarjant.[6]

It will be seen from Fig. 45 that α based on the calculated flame temperature is not very variable and does not appear to depend on gas rate, gas temperature, roof temperature, output (not shown), or roof pressure. There is a slight correlation with the fourth-power temperature difference (Fig. 45*a*) and with billet size (Fig. 45*f*); α' (based on the A row temperature), however, shows marked correlation with the fourth-power temperature difference, the gas temperature, and the roof temperature. There is also slight evidence that α' increases with increasing furnace pressure.

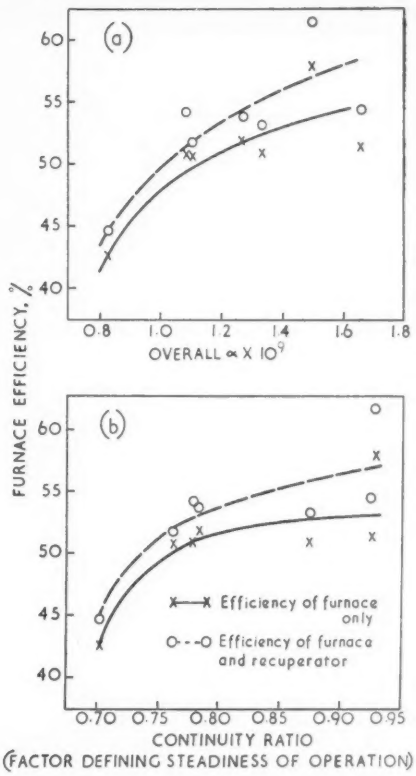


Fig. 46—Relationship between furnace efficiency and heat transfer

Since there is no reason to expect variations of α' with fourth-power temperature difference, these correlations suggest that the use of A row temperature is not as good as the use of the calculated flame temperature. This may be due either to inaccuracies of measurement or to the fact that the true burner-end conditions are not represented. A low A row temperature would give a low value of $(T_F^4 - T_S^4)$ and thus an apparently high value of α'. The fourth-power temperature difference is found to be related to average furnace temperature, thus explaining the correlations shown on Fig. 45*c* and *d*. It would thus appear that the coefficient based on the calculated flame temperature is the more reasonable. The average value of α on this basis was $1{\cdot}25 \times 10^9$ B.Th.U./sq.ft. hr. °F.[4]

Eberhardt and Hottel have evaluated P_f' from a number of tests:

$$P_f' = 1{\cdot}2\, C.P_g,$$

where C is a continuity ratio (actual output/output under steady conditions) and P_g is the gas emissivity. Now P_f' is the only variable likely to affect α, and so the continuity ratio and the gas emissivity should be the controlling factors. If the flame or gas stream is considered to be virtually constant in composition

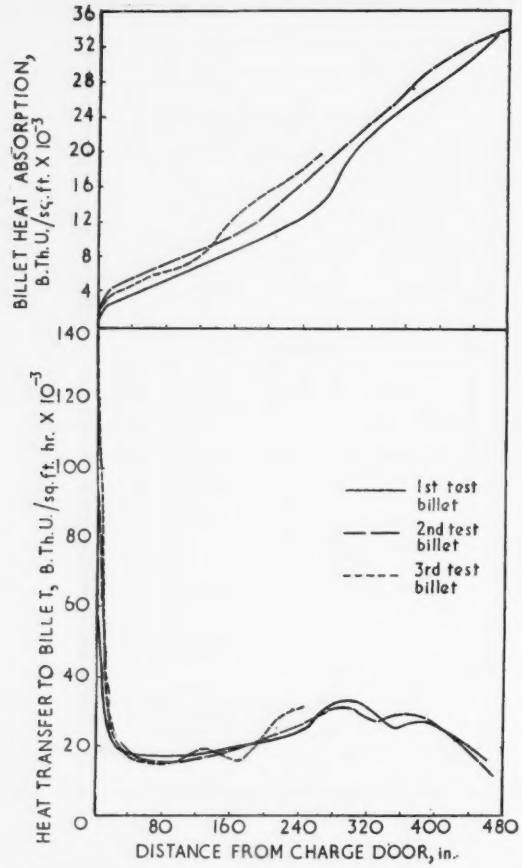

BILLET HEAT ABSORPTION, B.Th.U./sq.ft. X 10⁻³
HEAT TRANSFER TO BILLET, B.Th.U./sq.ft. hr. X 10⁻³
1st test billet
2nd test billet
3rd test billet
DISTANCE FROM CHARGE DOOR, in.

Fig. 47—Heat transfer to test billets: test 6 (2½-in. billets)

and shape, the controlling variables will be continuity ratio and gas temperature. Higher temperature would result in a reduction of P_g (for non-luminous radiation), and thus of P_f' and α. A higher continuity ratio would result in an increase of P_f' and α. The pseudo emissivity, P_f', also affects A' (and thus α in the opposite sense) but it is estimated that an increase in P_f' will cause an increase in α.

The continuity ratio has been calculated as the ratio of average hourly pushing rate over a whole test to the maximum rate obtained over any 1-hr. period. These are shown in Table IX, and Fig. 45*g* shows that the correlation between α and the continuity ratio is good and occurs in the sense expected.

The overall fourth-power heat-transfer coefficient is related to the efficiency of the furnace, as shown in Fig. 46*a*. The efficiency increases as α increases, and the correlation with efficiency is far better than with any factors previously examined. In Fig. 46*b* a similar curve is obtained with the continuity ratio. Increased efficiency is therefore the result of a high continuity ratio and a high overall rate of heat transfer as well as high output rates. In these tests, in fact, owing to circumstances mentioned earlier, the efficiency was not greatly dependent on output, and the regularity of operation has proved to be a most important factor.

Heat-Transfer Distribution

The quantity of heat absorbed by the test billets in their passage through the furnace has been assessed from the billet temperature distribution, which was calculated from the measured top and bottom temperatures, as described in the section on steel temperature variations. For every test billet the temperature distribution has been calculated at each 100° C. increment of top temperature. Thus, the heat content of the steel at these points has been derived and also the rate of heat pick-up in the intervals. These have been plotted against distance along the furnace hearth, and Fig. 47 shows the results for test 6 (2½-in. billets). All the other test billets exhibited similar tendencies, showing a low heat-transfer rate at about 80–120 in. from the charge door; this minimum tended to be further away from the charge door when heating thicker billets. There is then a maximum rate of heat transfer (apart from the very high initial rates) between the *C* and *B* rows in the furnace (220–360 in.

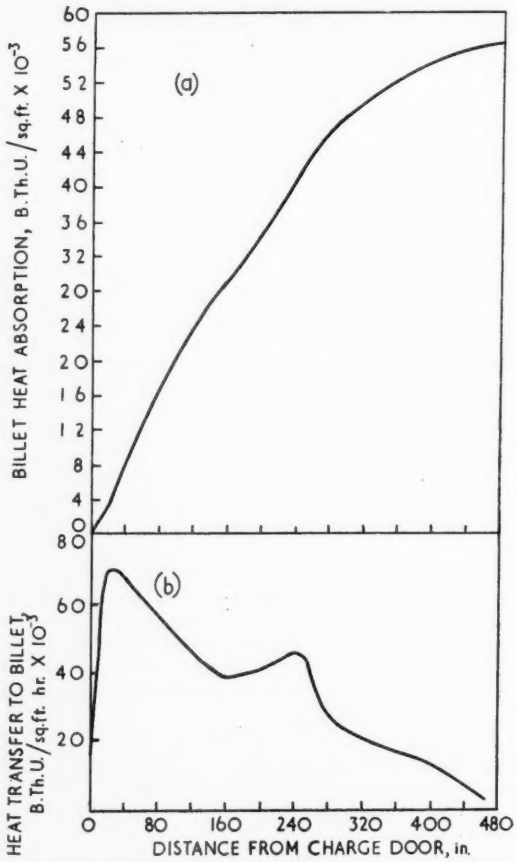


Fig. 48—Heat transfer to 4-in. billet heated in 100 min. (idealized curves)

Table X

TOTAL HEAT PICK-UP AND AMOUNT OF HEAT TRANSFERRED

Column *a*: Total heat pick-up at end of each section, 10^3 B.Th.U./sq. ft.
Column *b*: Amount of heat transferred in each section, % of total heat pick-up

Test No.	Billet No.	Charge Door to *D* Row		*D* Row to *C* Row		*C* Row to *B* Row		*B* Row to *A* Row		*A* Row to Discharge	
		a	b	a	b	a	b	a	b	a	b
1	i	8·4	29·8	15·0	23·4						
(2 in.)	ii	5·4	19·2								
	iii	6·6	23·4	12·9	22·3						
3	i	7·0	20·1	15·2	23·5	28·2	37·2	34·7	18·6	34·9	0·6
(2½ in.)	ii	7·8	22·5	16·7	25·6	27·8	32·0	34·6	19·6	34·7	0·3
	iii			18·0		28·4	29·9				
5	i	13·4	28·0	25·0	24·2	39·2	29·7	47·4	17·2	47·8	0·9
(3½ in.)	ii	10·3	22·8	19·8	21·1	38·1	40·6	45·0	15·3	45·1	0·2
6	i	5·0	14·7	11·9	20·3	25·4	39·7	33·5	23·8	34·0	1·5
(2½ in.)	ii	6·8	19·7	14·6	22·6	27·0	35·9	34·0	20·3	34·5	1·5
	iii	6·0	17·5	16·8	31·6						
7	i	8·5	21·2	19·2	26·8	32·5	33·2	39·3	17·0	40·0	1·8
(3 in.)	ii	8·5	20·2	19·2	25·5	32·5	31·7	41·2	20·7	42·0	1·9
	iii	6·7	16·0								
Average of all tests			21·2		24·3		34·4		19·1		1·0
Length of zone, in.		70		146		141		106		17	
Ideal (4 in.)		14·8	26·3	37·2	39·8	52·0	26·3	56·0	7·1	56·3	0·5

Table XI

HEAT-TRANSFER COEFFICIENTS IN DIFFERENT PARTS OF THE FURNACE

Test No.	Billet No.	Heat-Transfer Coefficient, B.Th.U./sq.ft. hr. °F.				Fourth-Power Heat-Transfer Coefficient α_g, 10^{-8} B.Th.U./sq.ft. hr. °F.^{4}			
		Charge to *D* Row	*D* Row to *C* Row	*C* Row to *B* Row	*B* Row to *A* Row	Charge to *D* Row	*D* Row to *C* Row	*C* Row to *B* Row	*B* Row to *A* Row
1	i	32·1	29·6	—	—	3·05	0·943	—	—
	ii	12·5*	—	—	—	1·57*	—	—	—
	iii	30·3	20·3	—	—	3·76	—	—	—
3	i	35·3	17·6	41·2	58·9	4·52	0·788	1·024	0·827
	ii	30·3	22·5	49·9	52·6	3·69	0·960	1·145	0·892
	iii	—	—	42·7	—	—	—	0·982	—
5	i	46·7	36·8	34·9*	51·1	4·40	1·327	0·713*	0·667
	ii	43·4	25·6	67·8	22·1*	4·27	1·016	1·375	0·252*
6	i	28·2	23·3	50·5	80·5	3·36	1·140	1·350	1·210
	ii	37·6	26·0	62·2	79·4	4·36	1·157	1·440	1·120
	iii	34·7	27·8	—	—	4·00	1·175	—	—
7	i	43·0	32·8	71·4	140·0	5·40	1·345	1·580	2·090
	ii	44·6	35·6	62·8	110·5	5·57	1·550	1·445	1·605
	iii	32·2	—	—	—	11·22	—	—	—
Average		34·7	27·1	52·0	58·6	4·01	1·14	1·23	1·06

* Low values due to stoppages

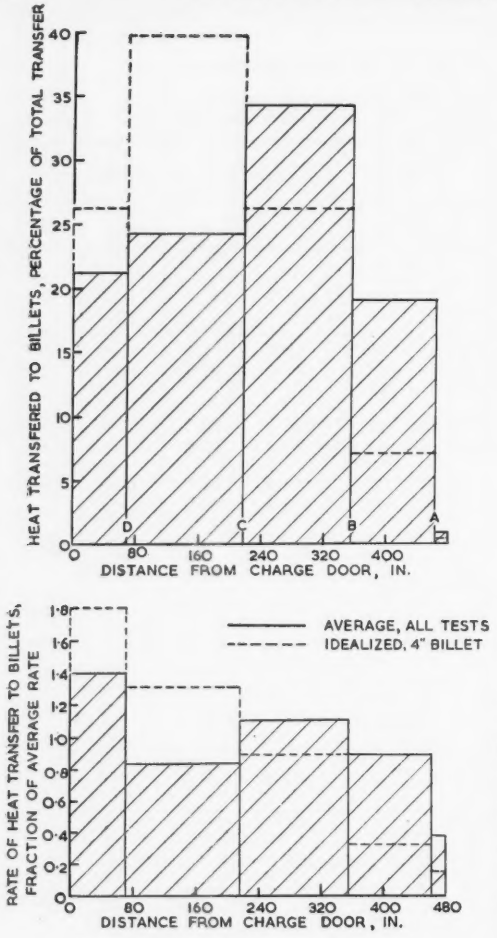


Fig. 49—Heat-transfer distribution

from charge door), the rate then falling slightly to discharge. For the purposes of comparison, similar curves have been constructed from the idealized heating curves (Fig. 42) for a 4-in. billet heated in 100 min. These are shown in Fig. 48, and the differences will be immediately apparent. Apart from the peculiarity due to the steel change point, the heat-transfer rate falls steadily from 70,000 to 3500 B.Th.U./sq. ft./hr.

To study the factors affecting the heat-transfer distribution, the heat quantities per sq. ft. of surface have been tabulated at the *D*, *C*, *B*, and *A* rows, and also at the discharge point. The furnace is thus divided into five parts and the amount of heat transferred in each section is shown in Table X.

Table X is of particular interest in that it shows where the heat transfer takes place: 21% occurs in the first 6 ft., 24% in the next 12 ft., 34% in the next 12 ft., and 20% in the last 10 ft. Figure 49 shows these figures in the form of a histogram, and the figures from the 'ideal' curves are shown as broken lines.

Too much heat seems to be transferred in the hotter zones and not enough at the colder end of the furnace. As already mentioned, this could be rectified by two-zone firing with the second zone in the region of the *B* row.

To determine whether the heat-transfer distribution is affected by other furnace factors, the percentage of heat transferred in each zone has been plotted against other variables. The scatter is so great that no very definite tendencies are apparent.

Sectional Heat-Transfer Coefficients

The sectional heat transfer so far considered takes no account of the temperature difference, and to determine the variation of the coefficient per ° F. or per ° F.^{4}, the measured temperature differences (gas to steel) and the fourth-power temperature differences have been calculated from the measured terminal temperatures for each section for the period during which each test billet was in the furnace. Table XI shows the heat transfer per ° F. in each section, and also α_s in the equation

$$q_s = \alpha_s A_s (T_{F(s)}^4 - T_{S(s)}^4).$$

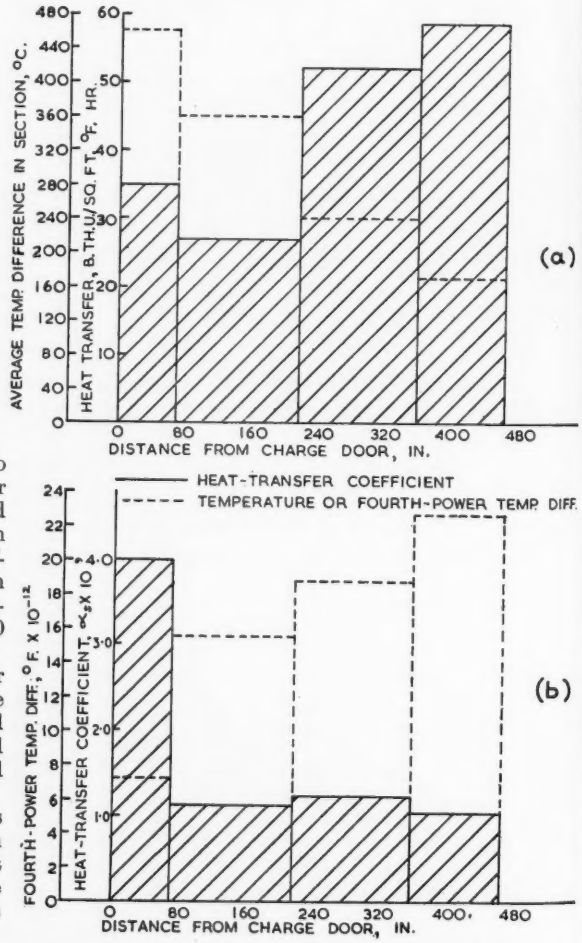

AVERAGE TEMP. DIFFERENCE IN SECTION, °C.
HEAT TRANSFER, B.TH.U./SQ. FT./°F./HR.
DISTANCE FROM CHARGE DOOR, IN.
(a)
HEAT-TRANSFER COEFFICIENT
TEMPERATURE OR FOURTH-POWER TEMP. DIFF.
FOURTH-POWER TEMP. DIFF., °F. X 10⁻¹²
HEAT-TRANSFER COEFFICIENT, α_s X 10
DISTANCE FROM CHARGE DOOR, IN.
(b)

Fig. 50—Distribution of heat transfer and gas-steel temperature-difference

Table XII

HEAT-TRANSFER COEFFICIENTS

(*a*) Overall Heat-Transfer Coefficients, B.Th.U./sq.ft. hr. ° F.

Test No.	1	2	3	4	5	6	7
Measured heat-transfer coefficient	34·1		30·0		36·5	37·0	49·9
Calculated coefficient (Schack)	40·1	43·3	42·3	46·3	46·6	40·8	39·7
Calculated coefficient (Heiligenstaedt)	30·2	32·3	31·6	34·3	34·6	30·6	29·9

(*b*) Average Values of Sectional Heat-Transfer Coefficients, B.Th.U./sq.ft. hr. ° F.

Furnace Section	*A–B* Row	*B–C* Row	*C–D* Row	*D* Row–Charge
Measured coefficient	58·6	52·0	27·1	34·7
Calculated coefficient (Schack)	64·2	46·8	30·03	7·23
Calculated coefficient (Heiligenstaedt)	46·3	34·4	23·45	8·22

where the symbols now refer to a specified section of the furnace.

The average gas–steel temperature differences for all the billets and the heat transfer per ° F. are shown for the different furnace sections in Fig. 50*a*, where it is seen that the temperature difference decreases from the cold to the hot end, but the heat-transfer coefficient shows a minimum in the *D–C* zone, the highest rate being in the *B–A* zone. The fourth-power temperature difference, however, increases from the colder zones to the hotter zones and α_s (the heat-transfer coefficient based on the average difference of fourth-power absolute temperatures) is virtually constant in all but the first zones (charge to *D* row). Figure 50*b* shows that in this zone the coefficient is about four times the average value for the rest of the furnace.

Attempts have been made to determine the reasons for changes in the coefficients in the various sections. The coefficient per ° F. and also for the fourth-power temperature differences have been plotted against temperatures and temperature differences in Fig. 51. This shows that the heat-transfer coefficient (in B.Th.U./sq. ft. hr. ° F.) increases with reduced temperature differences and with higher average gas temperatures. Since the small temperature differences are associated with high gas temperatures, this feature is explained by increased radiation. In other words, a given temperature difference is more effective at high temperature levels, which follows, of course, from the laws of radiation. However, the correlation is not so good in the higher temperature zones, which indicates lower accuracy in the measurements of hot-zone gas temperatures.

It is interesting to compare the measured values of the heat-transfer coefficient with those calculated from the formulæ of Schack[7] and Heiligenstaedt[8]:

Schack formula $C = 10{\cdot}25 + 0{\cdot}0922\,(t - 700)$
Heiligenstaedt formula $C = 10{\cdot}25 + 0{\cdot}0615\,(t - 700)$,

where t represents the average furnace temperature in ° C. and the constants have been changed so that C is given in B.Th.U./sq.ft. hr. ° F. These values are shown in Table XII.

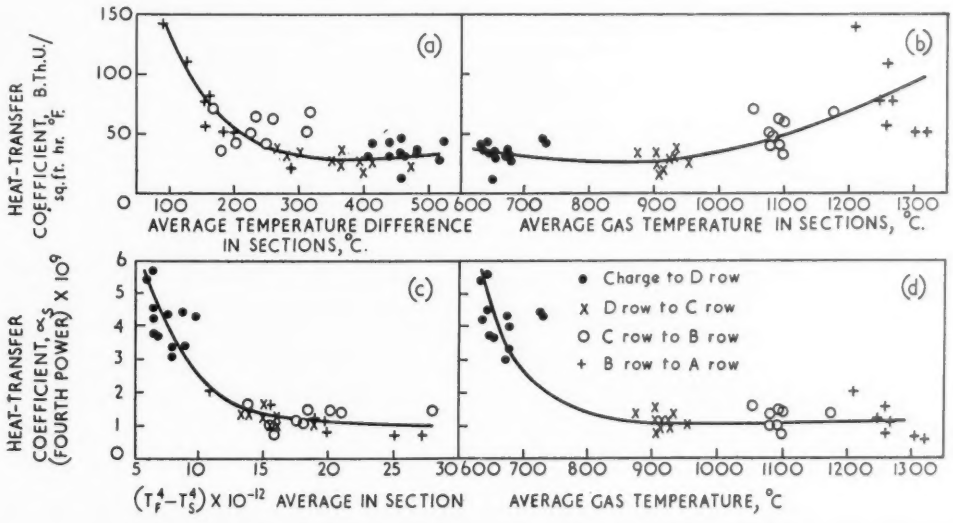

HEAT-TRANSFER COEFFICIENT, B.Th.U./sq.ft. hr. °F.
(a)
(b)
AVERAGE TEMPERATURE DIFFERENCE IN SECTIONS, °C.
AVERAGE GAS TEMPERATURE IN SECTIONS, °C.
HEAT-TRANSFER COEFFICIENT, (FOURTH POWER) X 10⁹
(c)
(d)
Charge to D row
D row to C row
C row to B row
B row to A row
(T_F⁴−T_S⁴) X 10⁻¹² AVERAGE IN SECTION
AVERAGE GAS TEMPERATURE, °C

Fig. 51—Inter-relation of temperature and heat-transfer coefficients

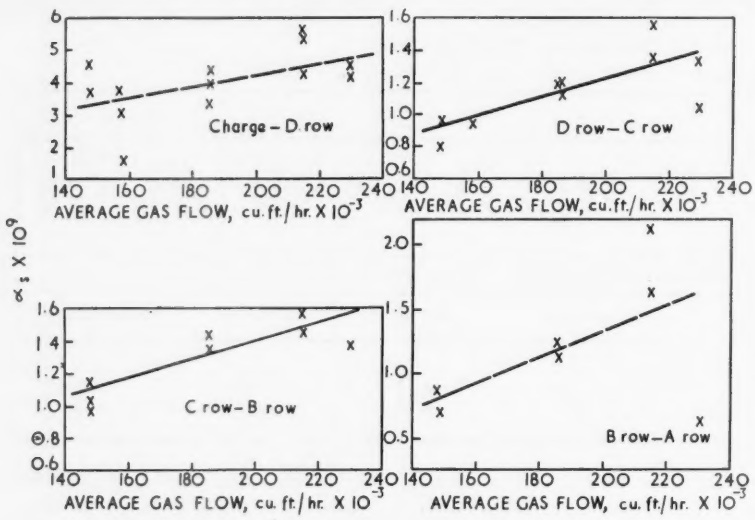


Fig. 52—Effect of gas rate on heat-transfer distribution

The calculated coefficients are thus of the same order as the measured ones, the Schack coefficient being generally slightly high and the Heiligenstaedt figure low. A constant of between 0·07 and 0·08 would appear to give the best results for this furnace: *i.e.*, coefficient $C = 10{\cdot}25 + 0{\cdot}075\ (t - 700)$. A serious discrepancy occurs in the *D* row to charge section of the furnace where the calculated figures are much lower than the measured ones. The gas temperatures recorded in this section of the furnace are lower than those reported by Schack and Heiligenstaedt, the terminal temperature having been measured in the flue in the present case. This may partly account for the differences observed.

Examination of the variation of α_g (the coefficient derived from the fourth-power temperature difference) shows a fairly constant value except at the charge end of the furnace, where the fourth-power temperature difference and the local gas temperature are low. This is partly due to having assumed the terminal gas temperature to be that of the waste-gas flue, which may result in low fourth-power temperature differences and hence high coefficients. The greater importance of convection at the cooler zones will also contribute; in addition, the steel receives heat from its undersurface when it is over the flue, whereas only the top surface area has been used in the calculations.

There is evidently not much variation from test to test in the heat-transfer coefficient or its distribution in the furnace. Figure 52 shows that the coefficient tends to increase with increased gas flow, although there is no evidence of a preferential change in particular zones of the furnace.

Sectional Heat Balances

The calculation of sectional heat balances is complicated by three factors:

(i) Combustion is not completed until the gases have travelled at least three-quarters of the length of the furnace, and so the amount of potential heat in the gases at any point cannot be determined with any accuracy

(ii) Owing to considerable quantities of air infiltration at one end of the furnace and combustion - gas blow-out at the other, the volume of gas involved varies throughout the furnace and is not accurately known at every section

(iii) Heat is transferred between zones by radiation.

If the ratio of heat given up by the gas to that absorbed by the steel (overall value 1·26) is calculated in each section, using a gas volume that is between the two extremes, the sectional ratios are:

Charge to *D* row	1·725
D row to *C* row	0·671
C row to *B* row	0·860
B row to *A* row	1·173
A row to discharge	26·4
Overall	1·26

The very high figure for the discharge to *A* row (a very small length) is due to two factors:

(i) The flame is assumed to have generated its total heat instantaneously, whereas some of the heat will actually be emitted up to *C* row

(ii) Some of the heat developed in the combustion zone will be radiated to other sections of the furnace.

Similarly, the impossibly low values in *B*–*C* and *C*–*D* zones are caused by no account having been taken of delayed combustion and inter-radiation; another cause is the fact that the gas volume will be at a maximum in those zones; for calculation purposes a mean has therefore been taken. The last zone (*D* row to charge) is probably the most accurate, since combustion is virtually completed and it will receive less heat by radiation. The volume, however, will be in error, since most blow-out occurs in this zone, resulting in a ratio that is on the high side.

This treatment serves no useful purpose unless the furnace is reasonably tight and the flame is short, and even then the re-radiation would have to be evaluated.

Schack[7] found a very similar effect even in a short-flame furnace and reports that the heat given up by the gas was less than that absorbed by the steel, because afterburning produced additional sensible heat.

PROPOSED FURNACE MODIFICATIONS

Certain limitations are imposed on the redesign of the furnace by the existing layout. These are, firstly, that the hearth must be of the same length and slope as at present, and, secondly, that the headroom at the rear of the furnace is limited by the crane-cab clearance.

In an earlier scheme, two-zone heating and oil firing were considered, but subsequent rises in oil prices made the retention of producer-gas firing more attractive. The modifications are, therefore, based on the latter fuel, which unfortunately precludes the use

Table XIII
SAVINGS IN FUEL

Basis: 9815 tons of coal per year (1950–1951)
Coal price (Nov., 1953) £3·472 per ton
Coal + steam £3·66 per ton

	Available Heat Fraction	Fuel Saving, %	Coal Saving, tons/year	Cost Saving, £/year
(*a*) Furnace under present conditions (no recuperator)	0·656	—	—	—
(*b*) Furnace with recuperator	0·769	14·7	1440	5280
(*c*) Furnace with recuperator: excess air reduced from 48% to 25%	0·806	18·6	1823	6670
(*d*) As (*c*) + blow-out reduced from 28% to 10%	0·839	21·8	2140	7840
(*e*) As (*d*) + removal of water-cooling, insulation of doors, additional doors, etc.	0·839	24·4	2395	8770
Total saving	£8770			

of two-zone heating, owing to the lack of headroom, the high cost of construction, and the difficulty of obtaining short enough flames in the limited furnace length. The following proposals have been made:

(*a*) The installation of a new burner end wall incorporating new turbulent-type burners directed approximately horizontally. These, when compared with the present vertical gas ports, will permit far better flame control and more rapid and efficient combustion; they will utilize the combustion space more effectively and reduce the tendency to inspirate cold air through the doors; they will enable the use of water-cooled dampers to be discontinued and allow the roof to be non-water-cooled, as the flame would no longer be in direct contact with it.

(*b*) The provision of a new roof which will not require water-cooling. It is felt that the roof contour could be changed in order to redistribute the heat transfer in the manner shown to be desirable.

(*c*) Since the hearth length is limited, it is proposed to pass the outgoing gases back underneath the billets for about a quarter of the hearth length before allowing them to pass to the recuperator. The effective length will thus be increased, leading to improvements in output and efficiency and enabling long flames to be used without too great a fall in efficiency, if this is found to be desirable.

(*d*) The replacement of the existing recuperator by a new one, giving a higher degree of preheat (450° C. max.), better accessibility, and no leakage. The hotter air and the provision for higher gas rates to make greater output possible will also necessitate alteration to the lining of the hot-air main, a larger air fan, and some modifications to the induced-draught fan.

(*e*) The furnace to be made more gas-tight and the insulation improved by:

(i) Fitting a door-clamping mechanism to all doors on one side of the furnace and lining them with insulation

(ii) Bricking up all door openings on the mill side of the furnace

(iii) Reducing the area of the charging door and of openings for pusher arms

(iv) Provision of power-operated doors at charge and discharge, which would be interlocked with the charging and discharging devices, to ensure that the doors are open for the minimum time.

(*f*) Full instrumentation, including automatic control of furnace pressure, gas/air ratio, and steel temperature, to be provided. The importance of furnace-pressure control was demonstrated during the trials, and improvements in combustion control and the quality of heating have also been shown to be desirable.

The furnace thus modified would enable greater outputs to be attained, and the fuel savings have been estimated as shown in Table XIII.

Item (*c*) is made possible by new burners and a tighter furnace, item (*d*) by a tighter furnace, and item (*e*) by the provision of new burners, new roof, and better doors and insulation. The automatic control would ensure that these savings were accomplished.

In addition to these fuel savings, the greater output possible (50 tons/hr.) would enable time to be saved on the large sections, and this reduction in time expenses has been estimated as about £10,000 per year. The total saving of about £19,000 per year is quite apart from the further profit on the increased output, which has not been considered. The scheme is therefore an attractive financial proposition.

CONCLUSIONS

(1) It has been agreed with the works production and engineering staffs that certain modifications to the furnace structure are desirable to enable greater outputs and improved efficiency to be attained. These include new burners, roof, and recuperator, better insulation, and improved gas-tightness. Fuel savings of more than 20% should be possible.

(2) The tests have emphasized the benefits of instrumentation and control. It has been suggested that furnace pressure, air/gas ratio, and steel temperature should be automatically controlled. Automatic gas-producer control is also desirable to ensure greater constancy of gas composition.

(3) Billet size has been found to affect the fuel consumption for a given rate of output; billets of 3 in. thickness and greater require more fuel and are associated with higher waste-gas temperatures at the same rate of output.

(4) The effect of furnace pressure has been investigated and found to have an important influence on fuel economy. A correlation with the amount of infiltrated air is given and a suitable operating pressure has been specified.

(5) The volume of combustion gas lost by blow-out has been shown to be large and of considerable importance in furnace operation.

(6) The progress of combustion in the furnace has been studied by taking gas samples by water-cooled probes. It is shown that the present burner system is incapable of effecting rapid combustion, unless the furnace pressure or air/gas ratios are held at inefficient levels. Correlations between combustion efficiency and gas flow illustrate the unsatisfactory nature and operation of the furnace controls.

(7) A technique of measuring the temperature of moving billets by thermocouples was developed and the steel temperature was used to evaluate the heat transfer to the stock. The factors affecting the internal temperature were examined and the improvements in soaking that could be effected by changing the time/top-temperature curve were assessed. In the present furnace, high rates of output are accompanied by high average furnace temperature, giving a high steel-top temperature at discharge, but a lower mean temperature and hence poorer soaking. It was also found that better soaking resulted when high furnace pressures and relatively low air/gas ratios were used.

(8) From conclusion (7) and a study of the rates of heat transfer during the passage of the billets through the furnace, it is evident that the only method of improving the soaking and at the same time of enabling more steel to be heated is to ensure a greater rate of heat transfer in the central region of the furnace. Two-zone heating would be the obvious way of doing this, but practical difficulties have resulted in other recommendations being made (*see* preceding section).

(9) The overall heat-transfer coefficients have been determined. Those based on the fourth-power temperature difference and the calculated flame temperatures at the hot end of the furnace were found to depend on the ' continuity ratio ' (actual output rate *vs.* output rate under steady conditions). For the short-period tests, the furnace efficiency did not correlate well with output or billet size, but it did depend on this continuity ratio.

(10) The heat-transfer coefficients (fourth power) are shown to be constant throughout the furnace length, with the exception of the cold end of the furnace, where very high coefficients were observed. The billets, however, receive some heat on their undersurfaces in this zone.

(11) Whilst the series of tests described have given valuable information on which to base the redesign of the existing furnace, it is not claimed that the results are applicable to all continuous reheating furnaces. The full value of the investigation will only be realized when other reheating furnaces are similarly tested and the results are compared with those for the present one. These first trials have provided valuable background information; future tests would be concentrated on the more important variables and the techniques would be modified on the basis of the experience gained. Attention would be directed to assessing the effect of design features on the process of combustion and the flame characteristics, the temperature distribution, and the heat transfer to the stock with particular reference to temperature equalization.

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APPENDIX

Bar-Mill Trial Data

All heat quantities are in 10^6 B.Th.U./hr.; all volumes are in cu. ft./hr. at 60° F., 30 in. of Hg, and dry (denoted by *S*), except where otherwise stated.

Test No. / Duration of Test, hr. / Billet Size, in.	1 8·0 2	2 7·75 3	3 8·0 2½	4 7·5 4	5 8·0 3½	6 7·6 2½	7 8·05 3
Producer Gas							
Dry-gas analysis: CO_2	6·3	6·2	6·3	6·2	6·3	8·0	5·62
O_2	0·4	0·1	0·1	—	—	0·4	—
CO	22·9	23·0	22·8	23·1	22·8	19·0	23·38
H_2	16·3	15·1	14·0	14·4	16·4	18·80	16·16
CH_4	3·3	2·8	3·2	3·8	3·2	3·85	3·06
N_2	50·8	52·8	53·6	52·5	51·3	49·95	48·22
Dry-gas calorific value, B.Th.U/cu.ft. (*S*)	161·0	152·1	151·9	160·5	159·9	162·0	159·5
Gas temperature, ° C.	490	525	455	465	510	515	500
Barometer, in. of Hg	29·70	30·0	29·7	29·5	29·7	29·65	30·00
Gas pressure at furnace (abs.), in. of Hg	29·71	30·02	29·71	29·51	29·71	29·66	30·01
Gas flow, cu. ft./hr. (*S*)	158,100	232,800	148,500	178,500	229,800	185,950	215,000
Tar content, grains/cu. ft. (*S*)	11·17	12·3	13·2	8·59	10·57	13·25	10·78
Water content, grains/cu. ft. (*S*)	32·2	33·6	35·9	22·2	29·2	33·70	25·53
Dew point, ° F.	113	115	117	100	110	115	106
Theoretical CO_2 content of dry gas (including combustion of tar), %	17·85	18·00	17·96	17·88	17·80	17·12	17·97
Theoretical air volume per cu. ft. of dry gas	1·475	1·441	1·467	1·443	1·471	1·539	1·470
Theoretical dry W.G. volume per cu. ft. of gas	2·055	2·036	2·071	2·029	2·037	2·089	2·004
Theoretical wet W.G. volume per cu. ft. of dry gas (includes only moisture of combination)	2·305	2·266	2·300	2·265	2·283	2·379	2·247
Potential heat input in gas	25·45	35·40	22·55	28·60	36·75	30·15	34·30
Sensible heat in gas	2·66	3·74	2·29	2·84	4·02	3·36	3·60
Potential heat in tar	4·01	6·50	4·45	3·48	5·52	5·88	5·53
Sensible heat in tar	0·11	0·19	0·11	0·09	0·15	0·16	0·14
Latent heat of water in fuel	0·64	0·99	0·68	0·44	0·82	0·79	0·65
Sensible heat of water and water vapour in fuel gas	0·30	0·49	0·29	0·22	0·41	0·39	0·33
Total Heat Input in Fuel Gas	33·17	47·31	30·37	35·67	47·67	40·73	44·55
Equivalent to heat input of B.Th.U./cu. ft. of gas (*S*)	209·5	203·0	204·5	200·0	205·5	219·0	207·2
Steel							
Billets per hr.	144·5	106·9	89·7	42·8	56·8	118·0	86·2
Av. heating time per billet, hr.	1·60	1·44	2·06	2·71	2·32	1·57	1·79
Charged weight, tons/hr. (calculated from lengths of billets)	23·30	39·65	22·30	26·33	28·90	30·22	32·35
Hearth loading, lb. of steel per sq. ft. per hr.	40·9	69·7	39·2	46·3	50·8	53·1	56·8
Hearth utilization, %	83·8	86·50	82·5	81·1	88·0	83·8	88·1

APPENDIX *(continued)*

Test No. Duration of Test, hr. Billet Size, in.	1 8·0 2	2 7·75 3	3 8·0 2½	4 7·5 4	5 8·0 3½	6 7·6 2½	7 8·05 3
Steel (contd.)							
Finished weight, tons/hr.	22·36	37·48	21·09	25·19	27·59	28·89	31·23
Percentage of charged weight	95·98	94·51	94·61	95·69	95·48	95·62	96·44
Scrap and crops, tons/hr.	0·45	1·46	0·85	0·66	0·81	0·59	0·76
Percentage of charged weight	1·91	3·69	3·79	2·50	2·79	1·95	2·42
Scale (difference), tons/hr.	0·49	0·71	0·36	0·48	0·50	0·74	0·36
Percentage of charged weight (av. = 1·80%)	2·11	1·80	1·60	1·81	1·73	2·43	1·14
Av. temp. at 2nd stand, ° C.	1171	1162	1160	1124	1155	1145	1136
Av. temp. by radiation pyrometer, ° C.	—	—	—	—	—	1296	1306
Av. temp. by roof optical pyrometer at *A* row, ° C.	—	1205	1233	1219	1265	1262	1291
Av. final top temp. by couples in test billets, ° C.	1210 (1 billet)	—	1220 (3 billets)	1250 (1 billet)	1230 (2 billets)	1207 (2 billets)	1220 (2 billets)
Av. top–bottom temp. difference by couples, ° C.	40	—	55	90	120	60	80
Difference between top couple temp. and 2nd-stand optical temp., ° C.	50	—	55	110	90	55	90
Estimated av. top temp., ° C.	1220	1250	1215	1235	1245	1220	1220
Av. mean temp. at discharge = top—⅔(top–bottom), ° C.	1194	1190	1179	1175	1165	1180	1166
Heat content, B.Th.U./lb. above 60° F.*	355·2	354·1	351·0	349·7	346·8	351·1	347·0
Heat to steel per hr.	18·55	31·49	17·55	20·64	22·47	23·80	25·15
Heat per hr. from scale formation at 2487 B.Th.U. per lb. of iron lost	2·64	3·985	1·988	2·660	2·780	4·090	2·065
Gas per ton of steel	6790	5880	6660	6780	7950	6160	6650
Therms per ton of steel	14·20	11·93	13·60	13·56	16·33	13·49	13·78
Air							
Wet-bulb temp., ° C.	54·5	52·3	51·70	39·6	43·55	55·3	57·0
Dry-bulb temp., ° C.	60·2	56·1	54·95	43·8	47·62	61·7	71·8
Relative humidity, %	69	77	80·5	69·5	73	67	39
Air volume delivered to recuperator, cu. ft./hr. (*S*)	485,000	501,500	453,000	510,000	507,000	345,000	549,000
Pressure before recuperator, in. W.G.	11·33	11·05	11·61	12·24	12·32	9·92	10·67
Pressure after recuperator, in. W.G.	5·53	2·75	5·00	4·59	5·21	2·03	—
Pressure drop across recuperator, in. W.G.	5·80	8·30	6·61	7·65	7·11	7·89	—
Air temp. after recuperator, ° C.	123	274	205·5	255	271·5	207	204
Air flow to furnace, cu. ft./hr.	220,000	349,500	279,500	293,500	293,000	310,000	306,000
Air lost by leakage across recuperator, cu. ft./hr. (*S*)	265,000	152,000	173,500	216,500	214,000	235,000	243,000
Measured air/gas ratio (*cf.* theoretical	1·39	1·50	1·88	1·645	1·275	1·667	1·423

* *See J. Iron Steel Inst.*, 1946, No. 2, pp. 83P–98P.

APPENDIX *(continued)*

Test No.	1	2	3	4	5	6	7
Duration of Test, hr.	8·0	7·75	8·0	7·5	8·0	7·6	8·05
Billet Size, in.	2	3	2½	4	3½	2½	3
Air (contd.)							
Air pressure after regulating valve, in. W.G.	0·71	1·28	0·79	0·69	0·69	—	—
Calculated air/gas ratio (from analysis before recuperator)	1·830	1·965	2·960	2·400	2·160	1·745	2·135
Total volume of air used in furnace (including infiltration), cu. ft./hr.	289,500	458,000	440,000	428,500	496,000	324,000	459,000
Air infiltration in furnace chamber, cu. ft./hr.	69,500	108,500	160,500	135,000	203,000	14,000	153,000
Air infiltration in recuperator (in addition to fan air lost)	145,500	206,500	239,000	138,000	128,500	55,500	65,000
Total air used (from all sources)	700,000	816,500	852,500	783,000	838,500	614,500	767,000
Heat in total cold air used (+ water vapour) above 60° F.)	+0·003	−0·060	−0·081	−0·235	−0·193	−0·019	+0·169
Heat in cold air infiltrated into furnace chamber (+ water vapour)	—	−0·010	−0·020	−0·040	−0·050	—	+0·034
Heat in dry preheated air	0·780	3·030	1·785	2·352	2·513	1·977	1·925
Heat in water vapour of preheated air	0·011	0·042	0·025	0·019	0·024	0·029	0·024
Total heat in air	0·791	3·072	1·810	2·371	2·537	2·006	1·949
Combustion and Waste Gas							
Temperature in furnace chamber	← See Table VI*a* →						
Analysis in furnace chamber	← See Table IV →						
Pressure at roof point *B*3, in. W.G.	0·0475	0·0415	0·034	0·035	0·035	0·0481	0·0393
Temp. before recuperator, ° C.	470	573	484	550	601	518	469
Draught before recuperator, in. W.G.	0·10	0·14	0·10	0·08	0·08	0·16	0·18
Analysis before recuperator:							
CO_2, %	15·29	14·40	10·5	12·16	13·38	15·43	13·37
O_2, %	2·24	3·27	7·5	6·35	4·72	2·28	4·50
CO, %	0·15	0·04	—	0·05	—	0·17	0·23
Calculated volume before recuperator (dry)	376,500	589,000	525,000	530,000	622,000	425,000	570,000
Measured volume before recuperator (wet)	272,500	496,000	419,500	495,000	480,000	400,000	480,000
Measured volume reduced to dry conditions	230,500	426,500	375,500	441,500	417,500	328,000	418,000
Combustion gas lost from furnace chamber by blow-out	146,000	162,500	149,500	88,500	204,500	97,000	152,000
Temp. of blow-out gases (taken as av. *D* row gas temp.), ° C.	850	850	840	890	915	830	805
Waste-gas/gas ratio (measured)	1·458	1·830	2·370	2·475	1·817	1·765	1·943
Waste-gas/gas ratio (calculated before recuperator)	2·38	2·53	3·54	2·97	2·71	2·287	2·653
Waste-gas/gas ratio (calculated after recuperator)	6·62	4·65	7·43	5·34	4·93	4·31	4·67
Temperature after recuperator, ° C.	142	256	179	241	280	176	193
Draught after recuperator, in. W.G.	0·39	1·03	0·41	1·02	0·93	0·63	1·06

APPENDIX *(continued)*

Test No.	1	2	3	4	5	6	7
Duration of Test, hr.	8·0	7·75	8·0	7·5	8·0	7·6	8·05
Billet Size, in.	2	3	2½	4	3½	2½	3
Combustion and Waste Gas (contd.)							
Analysis after recuperator:							
CO_2, %	5·47	7·52	5·0	6·80	7·33	8·28	7·72
O_2, %	12·22	9·86	14·8	12·60	11·29	10·55	10·66
Waste gas after recuperator per unit volume of gas before recuperator	2·78	1·84	2·095	1·80	1·82	1·885	1·762
Volume of waste gas after recuperator	641,000	785,000	788,000	796,000	760,000	618,500	736,000
Total air dilution in recuperator	410,500	358,500	412,500	354,500	342,500	290,500	318,000
Air infiltration in recuperator	145,500	206,500	239,000	138,000	128,500	55,500	65,000
Water per cu. ft. of waste gas (blow-out and to recuperator), lb.	0·00732	0·00660	0·00495	0·00507	0·00617	0·00852	0·00523
Dew point of waste gas before recuperator, ° F.	126·7	124·5	114·5	115·3	123·5	130·0	119·0
Water per cu. ft. of waste gas after recuperator, lb.	0·00301	0·00384	0·00266	0·00293	0·00356	0·0048	0·00368
Dew point of waste gas after recuperator, ° F.	99	108	95	99	106	111·7	103·3
Heat in dry waste-gas blow-out	4·680	5·180	4·630	2·940	7·040	3·025	4·415
Heat in dry waste gas to recuperator	3·835	8·770	6·315	8·650	7·990	6·090	6·660
Heat in dry waste gas after recuperator	2·760	6·520	4·38	6·18	6·98	3·42	4·50
Latent heat of water in blow-out	1·010	1·000	0·655	0·399	1·165	0·785	0·841
Latent heat of water in waste gas to recuperator	1·592	2·625	1·647	1·995	2·375	2·660	2·305
Latent heat of water in waste gas after recuperator	1·480	2·505	1·520	1·793	2·200	2·570	2·193
Sensible heat of water vapour:							
(*a*) In blow-out	0·782	0·785	0·535	0·347	1·008	0·586	0·527
(*b*) In waste gas to recuperator	0·620	1·300	0·715	0·996	1·257	1·144	0·935
(*c*) In waste gas after recuperator	0·180	0·560	0·262	0·412	0·559	0·350	0·363
Sensible heat of water:							
(*a*) In blow-out	0·032	0·030	0·017	0·010	0·036	0·029	0·028
(*b*) In waste gas to recuperator	0·050	0·089	0·042	0·052	0·070	0·098	0·076
(*c*) In waste gas after recuperator	0·027	0·057	0·025	0·033	0·048	0·077	0·059
Total heat loss in waste-gas blow-out	6·504	6·995	5·837	3·696	9·249	4·425	5·811
Waste gas to recuperator	6·097	12·784	8·719	11·693	11·692	9·992	9·976
Waste gas after recuperator	4·447	9·642	6·187	8·418	9·787	6·417	7·115
Structural Measurements							
Heat loss in cooling water:							
(*a*) From damper system	0·211	0·347	0·240	0·272	0·266	0·235	0·324
(*b*) From roof system	0·544	0·596	0·390	0·615	0·587	0·902	0·840
Total water-cooling loss	0·755	0·943	0·630	0·887	0·853	1·137	1·164
Heat loss by radiation and convection from brickwork and doors and unaccounted-for losses (by difference) from furnace and recuperator	5·557	2·165	2·073	4·454	7·898	9·022	7·206
As above, for furnace only	4·69	2·14	1·40	3·73	8·65	7·46	6·49
Heat loss to radiation and convection by calculation for furnace only	← 2·68 →						

Improvements in the Absorptiometric Determination of Tungsten

By the Methods of Analysis Committee

SYNOPSIS

The paper describes modifications to the absorptiometric method for the determination of tungsten published in an earlier paper. The solvent mixture has been modified and the titanous chloride addition has been increased. 962

As a result of further investigation by the B.I.S.R.A. Physico-Chemical Methods of Analysis Sub-Committee, the method described earlier* has been improved by a modification of the solvent mixture and by an increase in the titanous chloride addition.

Solvent Acid

Although the previously recommended acid mixture has proved to be a satisfactory solvent for many high-tungsten steels, calibration graphs show deviation from a straight-line relationship when the tungsten present exceeds the equivalent of 2½% of tungsten in a 1-cm. cell. An increase in the phosphoric acid concentration has been suggested by several correspondents, and it has been confirmed that by the addition of 6 ml. of phosphoric acid (sp.gr. 1·75) to the solution before fuming, this limitation may be overcome, enabling reliable results to be obtained on 6% tungsten steels by using 0·5-cm. cells or on samples containing over 6% of tungsten by using a reduced sample weight and adding pure iron to make a total of 1 g.

In the few cases in which the recommended acid mixture does not give complete decomposition, it is permissible to use alternative mixtures, provided that the fuming procedure removes hydrochloric and nitric acids to give a final solution containing approximately 6 ml. of sulphuric acid (sp.gr. 1·84) and 12 ml. of phosphoric acid (sp.gr. 1·75) per 100 ml.

* *J. Iron Steel Inst.*, 1952, vol. 172, pp. 413–415.

Table I

EFFECT OF MOLYBDENUM

Tungsten Added, %	Molybdenum Added, %	Negative Error (Tungsten, %)			
		Operator *A*	Operator *B*	Operator *C*	Operator *D*
2·5	Nil	Nil	0·01	Nil	0·01*
2·5	1·0	0·05	0·03	0·03	0·02*
2·5	2·0	0·11	0·07	0·10	−0·01*
2·5	3·0	0·13	0·14	0·27	−0·02*
0·5	3·0	0·04	Nil	0·16	...
5·0	3·0	0·34	0·29	0·22	...
2·5	3·0	Nil*	...	Nil*	...

* 1·0 ml. of titanous chloride added instead of 0·2 ml.

Molybdenum Interference

The effect of molybdenum up to 4% is overcome, as stated in the earlier report, by using titanous chloride as reducing agent. As the influence of this element varies according to the molybdenum/tungsten ratio, however, difficulties may arise with high-molybdenum steels (Table I). The addition of a further 0·8 ml. of titanous chloride solution (making a total of 1·0 ml.) to the final test solution entirely suppresses any molybdenum effect.

Copper Interference

Other procedures in which a thiocyanate reagent is used are affected by the presence of copper, which is precipitated if the solubility product of cuprous thiocyanate is exceeded. In the present method, 1% of copper shows no interference, but a slight precipitate is produced with 3% of copper; in the latter case a negligible error is introduced by the usual technique of filtering through a dry paper sufficient solution for colour measurement.

Results by the Modified Method

To confirm that the reproducibility of the method is not decreased by the modifications suggested above, it was applied to a series of samples similar to those examined in the earlier report; the results given in Table II*b* were obtained.

APPENDIX

Revised Draft British Standard Method for the Determination of Tungsten in Steel (Absorptiometric Method)

Section One : Introduction

Principle—The sample is dissolved in a mixed phosphoric–sulphuric acid solvent. After reduction of ferric salts by stannous chloride, a thiocyanate complex of tungsten is formed. Titanous chloride is

Paper MG/D/16/54 of the Methods of Analysis Committee of the Metallurgy (General) Division of the British Iron and Steel Research Association, received 30th April, 1954.

then added to complete the reduction and the resultant yellow colour due to tungsten is measured photometrically.

Range—Up to 3% of tungsten (Note 1).

Reproducibility—At 2% of tungsten, ± 0·05% of tungsten.

Vanadium causes interference in the method. If present, the amount must be determined by an independent method and a suitable correction must be applied to the tungsten figure (Note 5).

Section Two: Special Apparatus Required

A satisfactory apparatus for this method is the Hilger photo-electric absorptiometer. Using this instrument, suitable conditions for the determination of tungsten are:

Mercury vapour lamp
Ilford 601 filters, together with *H*.503 filters
1-cm. cells (range 0–3% of tungsten)
2-cm. cells (range 0–1·5% of tungsten)
4-cm. cells (range 0–0·7% of tungsten).

Other instruments of similar type may be used for which modifications of operational details will be required.

Grade *A* graduated glassware shall be used throughout.

Section Three: Reagents Required

All reagents shall be of the highest purity obtainable, and distilled water shall be used throughout. Solutions shall be freshly prepared each day and where necessary filtered.

Solutions

Phosphoric–Sulphuric Acid (3 : 3 : 14)—Add 150 ml. of phosphoric acid (sp.gr. 1·75) and 150 ml. of sulphuric acid (sp.gr. 1·84) carefully, with stirring, to about 600 ml. of water, cool, and dilute to 1 l.

Stannous Chloride (0·5%)—Dissolve 5 g. of stannous chloride ($SnCl_2.2H_2O$) in 500 ml. of hydrochloric acid (sp.gr. 1·16) and dilute to 1 l. with water.

Titanous Chloride—Dissolve 1 g. of titanium in 25 ml. of hydrochloric acid (sp.gr. 1·16), warming until solution is complete. Cool and dilute to 100 ml. with water.

Ammonium Thiocyanate (25%)—Dissolve 25 g. of ammonium thiocyanate in water and dilute to 100 ml.

Section Four: Sampling

Recommended methods of obtaining a suitable sample for the analytical procedure outlined below are described in B.S.1837.

Section Five: Procedure

Transfer 1 g. of sample (Note 1) to a 250-ml. beaker, add 40 ml. of phosphoric–sulphuric acid, and warm on a hotplate until action ceases. Add 6 ml. of phosphoric acid (sp.gr. 1·75), oxidize with nitric acid (sp.gr. 1·42), and evaporate to fumes (Note 2). Allow to cool, add 50 ml. of water, and digest until all soluble salts are redissolved. Filter if necessary (Note 3). Cool and dilute to 100 ml. in a graduated flask.

Pipette two 5-ml. fractions (*a* and *b*) into 50-ml. graduated flasks and treat as follows:

(*a*) *Test Solution*—Add 40 ml. of stannous chloride solution (0·5%), 3 ml. of ammonium thiocyanate solution (25%), and 1·0 ml. of titanous chloride solution, mixing well between each addition. Dilute to 50 ml. and mix thoroughly. Stand for 5 min. (Note 4).

(*b*) *Compensating Solution*—Add 40 ml. of stannous chloride solution (0·5%). Dilute to 50 ml. and mix thoroughly. Stand for 5 min.

Obtain the difference between the absorption reading of the test solution and that of the compensating solution, and convert to percentage tungsten from a calibration curve prepared under similar conditions (Note 5).

Section Six: Calibration

Standard Tungsten Solution—Dissolve 1·261 g. of high-purity tungstic oxide in 25 ml. of sodium hydroxide solution (10%). Dilute to 500 ml. with water in a graduated flask; 1 ml. of this solution contains 2·0 mg. of tungsten.

Procedure—Transfer five 1-g. samples of spectrographically pure iron to 250-ml. beakers, and add varying amounts of the standard tungsten solution for the appropriate range as follows:

4-cm. Cells		2-cm. Cells		1-cm. Cells	
Tungsten Solution, ml.	Equivalent Tungsten, %	Tungsten Solution, ml.	Equivalent Tungsten, %	Tungsten Solution, ml.	Equivalent Tungsten, %
0	0	0	0	0	0
1	0·2	2	0·4	4	0·8
2	0·4	4	0·8	8	1·6
3	0·6	6	1·2	12	2·4
4	0·8	8	1·6	16	3·2

Treat these samples as described in Section Five: Procedure.

Using the appropriate size of cell, obtain the difference between the absorption readings of the calibration-test solutions and the compensating solutions. Plot these differences against the percentage

Table II

COMPOSITION OF SAMPLES AND RESULTS BY MODIFIED METHOD

(*a*) Composition of Samples, %

Sample No.	C	Mn	Si	Ni	Cr	Mo	V	Co
MGS/78	0·6	0·65	0·2	0·3	0·5	0·04	...	...
/109	0·9	...	...	0·2	6·0	...	...	35
/124	...	...	...	8	18	...	...	...
/128	0·5	0·3	...	...	1·8	...	0·2	...
/233	0·3	...	0·5	3·5	1·3	...	0·2	...
/239	...	...	...	8	18	Nil	...	...

(*b*) Results by Modified Method (Tungsten, %)

Operator No.	Sample No. (MGS)					
	78	109	124	128	233	239
1	0·56	4·65	0·19	2·16	5·22	0·028
2	0·53	4·62	0·18	2·19	5·14	0·028
3	0·54	4·75	0·19	2·18	5·38	0·030
4	0·55	4·70	0·18	2·24	5·37	...
5	0·52	4·73	0·20	2·22	5·33	...
6	0·55	4·68	0·20	2·22	5·26	0·026
7	0·56	4·74	0·19	2·24	5·41	...
8	0·53	4·80	...	2·22	5·31	0·030
9	0·54	4·70	0·18	2·25	...	...
10	0·55	4·69	0·19	2·20	5·36	0·025
Av.	0·54	4·71	0·19	2·21	5·28	0·028

tungsten derived from the amount of standard tungsten solution added.

Section Seven: Calculation

The percentage tungsten is read directly from the calibration graph.

Section Eight: Notes

(1) In the case of samples containing over 3% of tungsten, a reduced sample weight made up to 1 g. with pure iron may be used; 0·5-cm. cells may also be used if desired.

(2) Other acid mixtures may be used to achieve decomposition of the sample, provided that nitric acid is removed by fuming and that the final solution contains approx. 6 ml. of sulphuric acid (sp. gr. 1·84) and 12 ml. of phosphoric acid (sp.gr. 1·75) in 100 ml.

(3) Samples containing large amounts of silicon may require filtration at this stage.

(4) In the case of samples containing more than about 2% of copper, cuprous thiocyanate may be precipitated. A negligible error is introduced by filtering sufficient solution through a dry paper to fill the absorptiometer cell, discarding the first runnings.

(5) Vanadium, if present, gives a colour similar to that produced by tungsten and in such cases the tungsten figure must be corrected, the vanadium content of the sample having been ascertained by an independent method. The magnitude of the correction is approx. 0·19%, to be deducted from the tungsten figure for each 1% of vanadium present, but the figure varies slightly with the tungsten content of the sample. For samples containing less than 0·3% of vanadium, no appreciable error will be introduced by assuming the correction to be independent of the tungsten content. For the highest accuracy in samples containing more vanadium, the correction graph should be prepared by carrying through calibration tests containing an amount of tungsten roughly equivalent to that in the sample, and varying amounts of vanadium.

The Problem of Rupture of the Billet in the Continuous Casting of Steel

By J. Savage, B.Sc., F.Inst.P., and W. H. Pritchard

SYNOPSIS

Rupturing of the billet skin in the mould is a long-standing problem in the continuous casting of steel. It is caused by a combination of high frictional forces between the billet and the mould surfaces and the relatively low tensile strength of the billet skin. Measurements of the friction between the billet and the mould and of the heat transfer through the mould wall, which are described in this paper, have led to a method for preventing rupture which has already been employed successfully on an industrial continuous-casting plant. 1031

As continuous casting has been so widely developed and used in the non-ferrous metal industry over the past 25 years, whilst a great deal of experimental work has also been done on steel, it is remarkable how few data have been published on the underlying physical principles of continuous casting. The process of casting liquid metal directly into billet or sheet form and thereby eliminating the conventional ingot stage was tried almost 100 years ago by Bessemer. The process was first proposed for steel, with the potential advantages of increased yield and the reduced costs of reheating, hot working, and of ingot moulds, but it does not appear to have operated successfully for steel until recent years. Continuous casting in the steel industry is still being actively developed, and a number of plants, which are essentially small-scale production units, are now either in operation or projected. Continuous casting has for many years been applied successfully to the production of aluminium, copper, and non-ferrous alloys.

Liquid steel loses heat by radiation at a very much higher rate than aluminium, and the liquid steel must therefore be cast at a higher rate to avoid premature freezing. With steel there is correspondingly a greater risk of the partly solidified billet being ruptured in the mould. This problem of rupture of the billet, combined with the technical difficulties of handling and pouring steel at rates lower than those used in conventional ingot casting, has probably been the major reason for the relatively slow progress in the commercial application of continuous casting to steel.

The difficulties due to rupture of the billet skin in the mould were first overcome by the development of a mould reciprocating technique. This system was developed by Junghans[1] about 20 years ago in Germany for the casting of non-ferrous metals, and since 1945 it has been applied to the continuous casting of steel by Junghans in Germany and by

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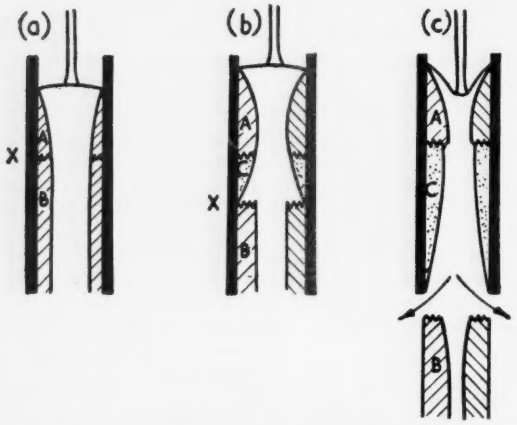

Fig. 1—Process following rupture of billet skin in the mould

Rossi in the U.S.A. The alternative casting technique adopted by Babcock and Wilcox[2] in the U.S.A., in which the billet is withdrawn intermittently from the mould, is fundamentally the same as the Junghans process. These and other methods which have been developed to minimize the problem of rupturing of the billet skin in the mould are now discussed.

RUPTURE OF BILLET SKIN IN A FIXED MOULD

Most workers who have carried out experiments on the continuous casting of steel have immediately run into the problem of rupture. The process which occurs in the mould after such a rupture was apparently first recognized by Greenidge.[3] His ideas have been further developed in the B.I.S.R.A. laboratories and the following theory is now believed to explain the nature of the process occurring in the mould after rupture of the billet skin.

The solidification boundary of the billet during normal continuous casting is shown in Fig. 1*a*. It is assumed that rupture of the skin occurs at *X* owing to the section *A* being stuck to the mould. The section *B* is withdrawn from the mould at a speed governed by the speed of the withdrawal rolls, and metal from the liquid core enters the gap between *A* and *B* and begins to solidify. Some time after rupture has occurred the section *A* is connected to the moving section *B* by a solidified section of steel *C* (Fig. 1*b*). Section *B* repeatedly tears from *C* at the point *X*, so that finally, when the position of *X* has moved to the bottom of the mould, liquid steel pours out from the liquid core and a solid crust or tube is left in the mould (Fig. 1*c*). When this process begins with a fixed mould, it is very unlikely that it can be stopped, owing to the very low cohesion between sections such as *B* and *C* shown in Fig. 1*b*.

The essential means of overcoming the failure of the continuous-casting process resulting from this incipient rupturing of the billet skin is to prevent excessive tensile stresses being applied between such sections as *B* and *C* (Fig. 1*b*). One method is to prevent relative movement for a time between sections *A*, *B*, *C*, and the mould, and so give the section *C* time to solidify sufficiently to form an adequately strong bridge between the parts *A* and *B*. There is then a greatly increased probability that the originally stuck section *A* of the billet, having cooled and contracted, will be detached from the mould and normal casting will re-occur. Evidence for the occurrence of this type of rupture can be obtained from heat-transfer measurements through the mould wall.

The rate of heat transfer at any position along the mould should be as shown by the broken line in Fig. 2*b*. The rate of heat transfer diminishes down the mould during normal casting and this effect is discussed quantitatively later. The region of maximum heat transfer is at the position of the billet skin when freezing begins and is level with the surface of the liquid steel in the mould during normal casting. However, after rupture occurs the region of maximum heat transfer will be at the position where the liquid steel is moving to the mould wall. At the particular time when the position of *X* is as shown in Fig. 2*a* the rate of heat transfer through the mould wall will be as shown by the full line in Fig. 2*b*. The peak of this modified heat transfer moves with the position of *X* along the mould at the same rate as that of the billet withdrawal. Consequently it is to be expected that if the average rate of heat transfer is measured through the mould for three sections such as *P*, *Q*, and *R* (Fig. 2*a*), then as the rupture progresses along the mould the total heat transfer in any of the zones will rise to a maximum as the position of the rupture passes through the particular section of the mould concerned.

Experimental observations of this phenomenon were made by placing thermocouples in the water-cooling annulus in the outer face of the mould. The results obtained are shown in Fig. 3. The temperatures are proportional to the heat transfer rate, and in all cases, after the initial heating up there is a rapid fall. This can only be explained by the build-up of a solid layer of steel inside the mould as

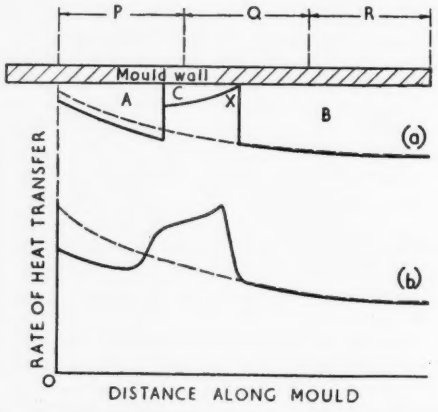

Fig. 2—Theoretical heat-transfer conditions through mould after rupture of billet skin

indicated by zone A in Fig. 2. The progressive shift of the maximum corresponds with the shift of zone C. It is to be expected that the time interval between the maxima shown in Fig. 3 will be d/v, where d is the distance between successive thermocouples and v is the velocity of withdrawal of the billet. This was found to be the case, so that the theory illustrated in Fig. 2 seems to be confirmed.

EXISTING METHODS FOR PREVENTING FAILURE OF CASTING PROCESS DUE TO RUPTURE OF BILLET SKIN

Two methods of continuous casting have been developed up to now to circumvent failure of the casting process resulting from rupture of the billet skin. The first of these is the Junghans process. The principal feature of this system is that the mould moves at the same speed as the billet for about 1 in., at which stage the mould is returned to its original position at about three times the speed at which the billet is withdrawn. This cycle of operations continues for the entire casting process so that there is no relative movement between the mould and the billet for about 75% of the time that any element of the steel is passing through the mould. The mechanical drive controlling the rate of the billet withdrawal also controls the mould movement. The probability of rupturing the billet skin is greatest at the time when the mould is returned to its highest position at a velocity of $3v$, where v is the casting velocity, and if rupture occurs it is taken to be at a position X, shown in Fig. 4*a*. The stuck section A of the billet skin may be carried upwards by the rapid movement of the mould while the section B attached to the withdrawal system moves down at a speed v. This breaking through the meniscus of liquid steel by a section such as A (Fig. 4*b*) has been observed by one of the authors (J.S.) at a steelworks where this method of continuous casting is in operation. During the next stage in the cycle, when the mould is moving down at the same velocity v as the billet, the liquid metal which has run into the gap formed between A and B solidifies to form the bridge C (Fig. 4*b*).

The thickness and tensile strength of section C increases throughout the time allowed for the downward stroke, reaching a maximum at the moment of the next upward movement of the mould. As this mould cycle operates a number of times while each section of the billet is passing through the mould, there is a good chance of any rupture being healed. It is, however, possible for the process to fail by persistent rupturing if the time for solidification allowed by the downward stroke of the mould is insufficient. This can occur when the mould stroke is too short or the casting velocity is very high.

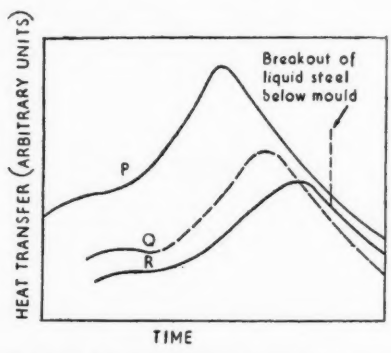

Fig. 3—Observed heat transfer through three zones of mould during process of rupture

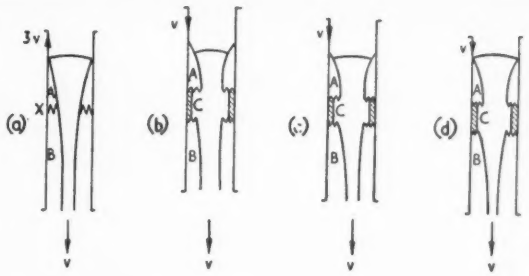

Fig. 4—Prevention of liquid steel break-out by Junghans reciprocating mould

The idea of using a fixed mould and withdrawing the billet intermittently appears to have been suggested first by Jacquet.[4] Fundamentally this method is identical with the Junghans process in that at several intervals of time during which the billet is passing through the mould, there is no relative movement between them. Consequently, if rupture of the billet skin occurs there is a period during which the billet withdrawal is stopped and in which the gap between the two ruptured sections can be bridged satisfactorily in exactly the same way as is shown for the Junghans process in Fig. 4. The disadvantage of the two systems described is that, owing to the rapid intermittent acceleration applied in one case to the mould and in the other to the billet, there is always the likelihood of rupturing occurring, followed by the bridging process which leads to tear marks on the billet surface. While these may not penetrate to any appreciable depth in the billet or give trouble in subsequent rolling or forging, they may with some steels necessitate very careful handling of the billets so as to avoid breaking at the tears. Nevertheless, the application of these two methods has enabled the process of continuous casting to be applied successfully to steel and has constituted a very important advance. If it is assumed that a period of t sec. is adequate for a strong enough bridge to form between two ruptured sections, then the time during which no relative movement should occur in the Junghans process is related to the distance the mould is moved at each stroke and the billet velocity by $l/v \sim t$. To ensure that the time for bridging is adequate, an increase of the casting velocity should be accompanied by an increase of the distance moved by the mould at each stroke. In the case of carbon steels t appears to be of the order of 1 sec. so that speeds of withdrawal of up to 5 ft./min. should be safe with a mould stroke of 1 in. If adequate lubrication is

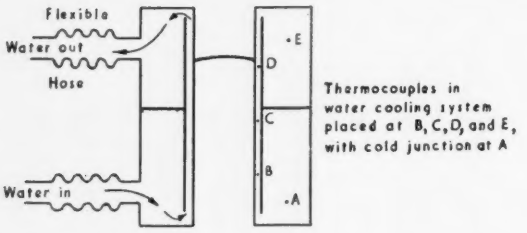

Fig. 5—Arrangement for water cooling of the mould

provided, as discussed later, this casting speed can be increased by a considerable factor.

Industrial Applications

Plants have been operated in Germany and in the U.S.A. using both of these casting methods. The first announcement of the successful application of continuous casting to steel was made by the Babcock and Wilcox Tube Co., Beaver Falls, U.S.A.[5] This plant is supplied with liquid steel from an electric furnace of a few tons' capacity. The mould is fixed and the billet withdrawn intermittently, this withdrawal being controlled automatically. The Junghans process was first operated successfully for steel at the Junghans works, Schorndorf, Germany, on an experimental basis and was later applied to a pilot plant at the Mannesmann Works, Huckingen, Germany, for the casting of carbon and low-alloy steels. The experience obtained in operating this plant has been reported by Speith and Bungeroth.[6] Since these first plants were built, the Junghans process has been applied on an experimental production basis at the Rheinische Rohrenwerke, Mulheim, Germany, and at a steelworks in Greece. The same process has also been developed by Rossi at the Allegheny Ludlum Works, Watervliet, U.S.A., where a wide variety of steels has been cast experimentally.[7] The Barrow Steelworks in conjunction with the United Steel Companies has also carried out successful works' trials on a Rossi continuous-casting plant for the production of 2-in. square sections of carbon steel at a very high withdrawal velocity of up to 20 ft./min.[8]

MEASUREMENT OF FRICTION BETWEEN BILLET AND MOULD

Since friction between the surfaces of the billet and the mould is primarily responsible for rupture, the magnitude of the friction was measured over a range of conditions. In the experimental work the moulds used were brass cylinders of 3-in. internal diameter and 13 in. in length, having a wall thickness of $\frac{1}{8}$ in. During casting the effective mould length used was 10 in. as the steel level was usually maintained about 3 in. from the top of the mould. The arrangement used for water cooling the mould is shown in Fig. 5. For measuring the friction between the billet and the mould, the mould M was mounted on springs as shown in Fig. 6.

Four springs (S) of equal rating were assembled symmetrically so that when a frictional force existed

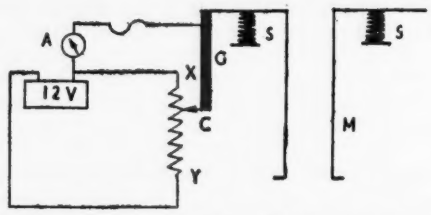

Fig. 6—System used to measure friction between billet and mould

between the billet and the mould the springs were compressed to a degree depending on the magnitude of the friction. The rigid slide-arm G was attached to a contact C which could move along a fixed potentiometer XY. The voltage across XC was applied across a recording milliammeter A, so that a continuous record of the friction was obtained during the casting.

Figure 7 shows typical friction records for several types of mould surface. Experiments were made with brass moulds in which the surface had been either honed, honed and polished, or chromium- or lead-plated. At this stage no lubricating oils were used. The lowest friction was obtained with the polished-brass mould, although in practice it would probably be very difficult to maintain the friction at this level for a long period and casting times of only a few minutes were possible in the laboratory. Chromium plating tended to produce an irregular and frequently large friction. This is interesting in view of the use of chromium-plated moulds on several of the semi-commercial plants now operating on a pilot scale. The behaviour of a lead-plated mould was rather surprising. It was considered that the use of a metal plating with a low shear modulus would result in a low friction being obtained. In nine experiments which were carried out with the

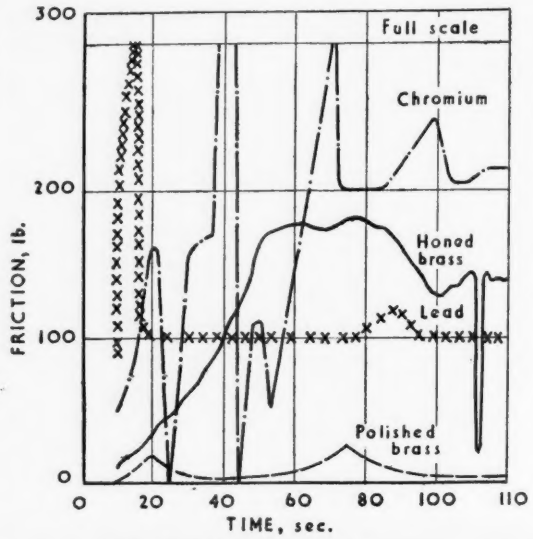

Fig. 7—Typical friction records

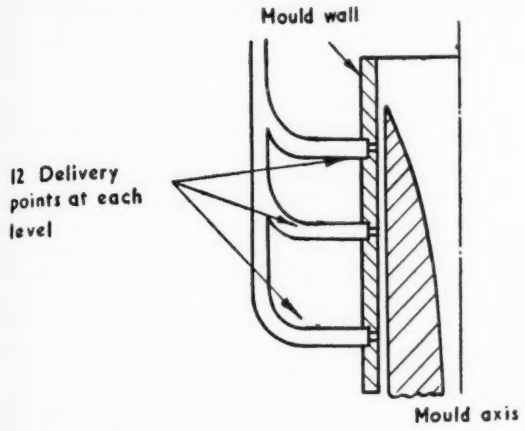

Fig. 8—Lubricant injection system

lead-plated brass mould the initial friction was so high that in all but one experimental cast total seizure of the billet in the mould occurred. In these eight cases the springs were compressed to their limit (at this stage about 1 in.) and the short length of billet cast was then broken by the force exerted by the withdrawal system.

As already mentioned, in these experiments the casting was carried out without the use of liquid lubrication. It might be thought that the maintenance of a lubricating film between the billet surface and the mould wall would be impossible in view of the high temperature of the billet. However, Krainer and Tarmann have shown[9] that the inner mould-wall temperature is of the order of 200° C. The actual temperature of the inner mould-wall is a function of the heat transfer, the mould-wall thickness, the thermal conductivity of the mould material, and the velocity of the cooling water along the outer face of the mould. Consequently, when these last three factors are chosen so that the inner face temperature of the mould does not exceed the boiling point of the lubricant injected, a liquid boundary layer of the lubricant may be expected to exist at the inner mould-face.

In the first series of experiments, vegetable and mineral oils were injected through the side of the mould, as shown in Fig. 8. Oilways cut into the mould wall distributed the lubricant at three levels over the length of the mould and at 12 points circumferentially at each level. This system of lubrication

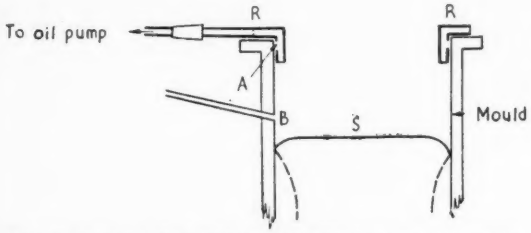

Fig. 9—Method for applying lubricant at the top of the mould

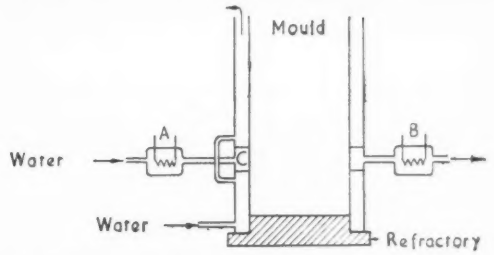

Fig. 10—Measurement of heat transfer rate during solidification of liquid steel

had to be abandoned as it was found that the lubricants, even when injected in quantities as low as 2 c.c./min. and distributed in the manner described, were liable to explode and blow a hole in the side of the billet wall. Before these explosions occurred the actual friction levels measured were very low indeed and lower than those obtained previously with an unlubricated polished-brass mould surface.

In a second series of experiments the lubricants were introduced at the top of the mould as shown in Fig. 9. A detachable oil-distributing ring which fitted the top of the casting mould was connected to an oil supply from which the flow rate was adjustable. The oil holes in the ring R were of $\frac{1}{32}$ in. dia. and spaced at intervals of about $\frac{3}{4}$ in. on the circumference of the ring at positions indicated by A. A difficulty is caused by a change in level of the meniscus S whenever a fluctuation of the steel supplied to the mould occurs. If the level of S is falling quickly the oil flowing on the mould wall may be moving too slowly and the value of the friction rises. This effect can be reduced by increasing the oil flow up to the limit at which visibility into the mould is not seriously impaired by the flame from the burning oil. It appears that about 25 c.c./min. of vegetable oil is a reasonable compromise for a mould with a periphery of about 10 in. For larger moulds greater oil rates could be used so that the oil supplied per unit area of the mould surface remains sensibly the same as that given. When the oil injected is so regulated, consistently low values of friction of 25 lb. or less may be expected. Gebrüder Bohler A.G. of Austria have injected oil through a channel similar to that indicated by B (Fig. 9) with satisfactory results.[10] By these methods very low frictional forces are obtained so that the danger of billet rupture is greatly reduced when casting continuously with a fixed mould.

Mineral oils at rates exceeding about 5 c.c./min. distributed in the manner described produced a dense smoke on burning at the steel meniscus, which obscured the visibility into the mould. It was found that rapeseed oil was much better in that a light semi-transparent flame was obtained without smoke at rates of up to 25 c.c./min. This is a decided advantage in the manual control of the casting operation.

ESTIMATE OF STRENGTH OF BILLET SKIN

The tensile force due to friction which the billet skin will withstand is related to the strength of the

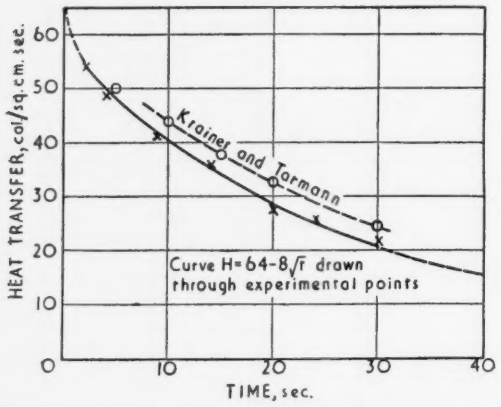

Fig. 11—Measured values of heat transfer through mould

steel. This strength will depend on the type of steel being cast, the thickness solidified, and the temperature of the steel. The last two variables depend largely on the time from the beginning of solidification, or on the level of the billet skin from the surface of the steel in the mould. The billet skin will be weakest where solidification is just beginning at the top of the mould, and for this reason it is important that the friction between the mould and the billet wall should be maintained at a low level in this region. The billet skin will be ruptured when the strength of the solidified steel at any level in the mould is less than the total frictional force above that level. For this reason comparatively high values of friction can be tolerated provided that this frictional force is only exerted in the lower part of the mould where the steel has become comparatively strong. To assess the strength of the steel skin, measurements were made on the rate of heat transfer, which governs the rate of freezing.

The rate of heat transfer through a copper mould under static conditions was measured by the apparatus shown in Fig. 10. The temperature difference between the ingoing and outgoing water passed through the sampling chamber C was measured by a cathode-ray oscillograph, which recorded the out-of-balance signal from two tungsten-wire resistance elements A and B. The system was calibrated from the Y-deflection of the C.R.O. against the temperature difference between the elements A and B. In this way the rate of heat transfer through the mould from the freezing steel was measured as a function of time. The mould-tube thickness was varied from $\frac{1}{16}$ to $\frac{1}{4}$ in. and the internal diameter of the mould from $1\frac{1}{4}$ to $2\frac{1}{4}$ in. These variables had very little influence on the rate of heat transfer at any time after the first few seconds; during this stage there were minor initial differences, probably owing to variations in the thermal capacities of the mould tubes used. The means of the experimental results for plain low-carbon steels are given by the crosses in Fig. 11.

Krainer and Tarmann obtained the rate of heat transfer in a continuous-casting mould, 8 cm. in diameter and 30 cm. in length, as a function of distance along the mould at a billet withdrawal velocity of 0·6 m./min. (1 cm./sec.). These workers attached thermocouples to the outer mould-wall and from the temperatures so measured derived the rate of heat transfer through the mould at several positions below the free steel surface. Their results have been redrawn and shown as a function of time from the beginning of freezing in Fig. 11. The two sets of data are in reasonable agreement when it is remembered that the results reported have been obtained by different methods.

The results obtained by the present authors are found to fit an empirical relationship:

$$H = 64 - 8\sqrt{t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where H=Rate of heat transfer, cal./sq. cm. sec.
t =Time from beginning of freezing, sec.

This relationship can only be approximate and applicable for values of t up to about 40 sec. (The heat transfer in conventional ingot moulds for periods of a few minutes up to several hours after pouring steel into the mould has been studied by several workers and the results have been summarized by Ruddle.[11])

An opportunity was found to test the relation given in equation (1) in the course of an investigation into the effect of the billet withdrawal velocity on the average heat transfer through the mould. In this series of experiments the mould was 25 cm. long and

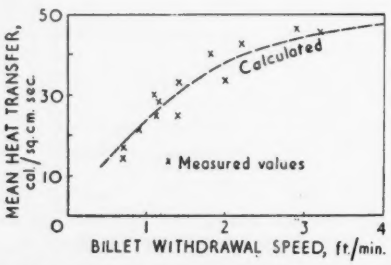

Fig. 12—Calculated and experimental values of heat transfer through mould

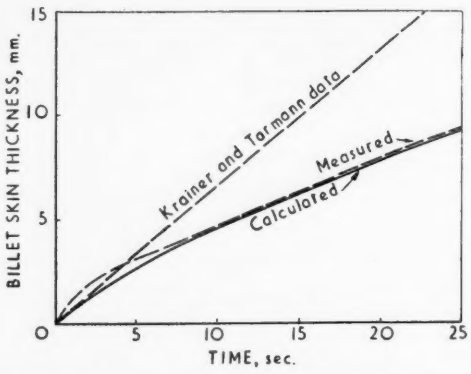

Fig. 13—Relation between billet skin thickness and time from beginning of freezing

the withdrawal velocity covered the range 0·25–1·5 cm./sec. (6 in.–3 ft./min.). From equation (1) the average heat transfer through the mould (H_a) from zero time to t sec. is

$$H_a = \frac{1}{t}\int_0^t H dt = 64 - \frac{16}{3}\sqrt{t} \quad \ldots\ldots\ldots\ldots(2)$$

For a billet withdrawal velocity of v cm./sec. and a mould length l cm.

$$H_a = 64 - \frac{16}{3}\sqrt{l/v} \quad \ldots\ldots\ldots\ldots(3)$$

By plotting values of H_a for the values of l and v given, the curve shown in Fig. 12 is obtained. The measured average values of heat transfer through the entire length of the mould obtained from a number of continuous-casting experiments on mainly 0·8% C steel are also shown and these are in reasonable agreement with the relation given in equation (3).

By using a simple theoretical treatment of the freezing process (*see* Appendix), the rate at which the billet solidifies may be calculated from the heat-transfer data obtained and the results can be compared with experiment.

If x is the thickness of steel solidified at t sec., L the latent heat of fusion, ρ the density, S the specific heat, k the thermal conductivity, and R the billet radius, it is shown that for small values of x/R, x is given by:

$$\frac{SHRx^2}{2Lk} + x(2R - x) - \frac{RQ}{\rho L} = 0 \quad \ldots\ldots\ldots(4)$$

where $H = 64 - 8\sqrt{t}$ and $Q = \int_0^t H dt$.

It is also shown that the billet surface temperature θ_2 is given by:

$$\theta_2 = \theta_1 - \frac{RH}{k}\log_e\frac{R}{R-x} \quad \ldots\ldots\ldots\ldots(5)$$

where θ_1 is the liquidus temperature, and R, H, k, and x are as given earlier.

The calculated values of x from equation (4) are shown in Fig. 13 and compared with measured values obtained by the well known 'run-out' method. This consists of piercing the billet skin below the mould and at the same time stopping the supply of liquid steel to the mould. These calculated and measured values are seen to be in good agreement but not with those of Krainer and Tarmann. It is not clear from their paper whether the results given by them are experimental or calculated values.

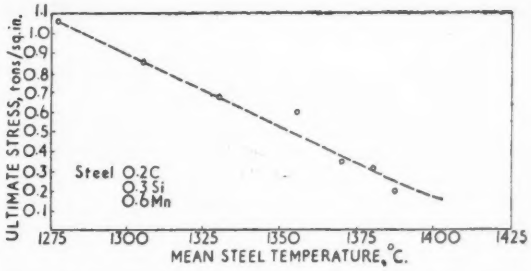

Fig. 15—Relation between ultimate tensile stress and mean steel temperature in cooling after casting[12]

The calculated values of the billet skin temperature are shown in Fig. 14. For a mould length of 25 cm. at a casting speed of 2 ft./min. (1 cm./sec.) the billet would be expected to emerge from the mould with a surface temperature of the order of 1150° C. Reliable measurements of this temperature are very difficult to obtain but optical-pyrometer determinations have indicated values of this order. The estimated mean temperature of the billet skin is also shown in Fig. 14.

It is now possible to make an estimate of the increase in strength of a continuously cast billet skin with time. This can be calculated from the skin thickness and its mean temperature at any point along the mould, together with the ultimate stress at that particular mean temperature. For the latter, use was made of the results obtained by Hall,[12] who measured the ultimate stress of 1-in. dia. ingots a short time after casting. From his data a curve was drawn (Fig. 15) showing the ultimate stress as a function of the mean temperature of the steel (in this particular case 0·2% C, 0·3% Si, 0·6% Mn). The calculated increase of the ultimate strength of the

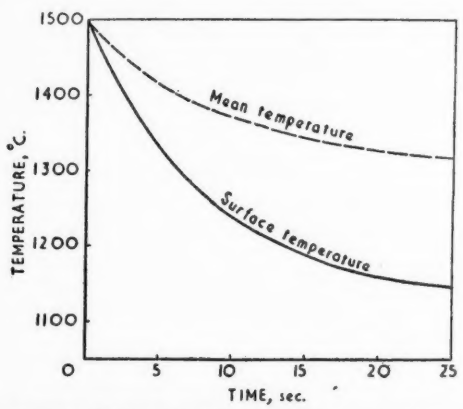

Fig. 14—Estimated billet surface temperature

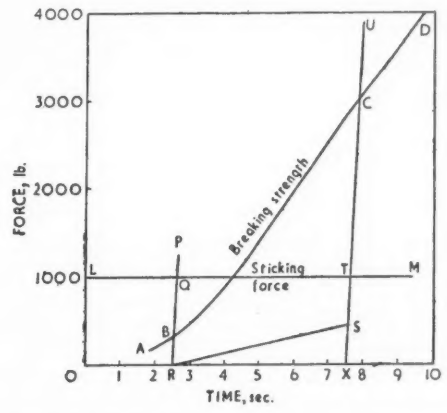

Fig. 16—Estimated force to break billet skin

billet skin with time is shown by curve AD in Fig. 16, and is discussed below.

THEORY OF THE ACTION OF A SPRING-MOUNTED MOULD

After carrying out casting experiments with the apparatus designed for measuring the friction between the mould and the billet, it became clear that the spring mounting of the mould was playing an important part in the mechanism of the casting process. Later experimental work confirmed that this system had considerable advantages compared with a fixed mould in reducing the probability of rupture of the billet skin. A theory of the action of the spring-mounted mould is now proposed.

In Fig. 16, $ABCD$ shows the breaking strength of the solidified billet skin as a function of time from the beginning of freezing, calculated for a 0·2% C steel billet, 3 in. in diameter. It is assumed that the sticking force between the mould and the billet surface is concentrated at the weakest part of the billet skin just below the meniscus.

Whilst it is difficult to predict the distance below the meniscus at which the billet skin may stick to the mould, experience has shown that it is about 1 in. at a casting speed of 24 in./min. In such a case the billet skin, at which rupture will occur if the applied tensile force is sufficiently high, will have been freezing for about 2½ sec. The strength of the solidified skin at this position is given in Fig. 16 by the distance RB, representing a breaking strength of about 300 lb. If the billet sticks with a force which exceeds this value, then in a fixed mould the rapid rise of the tensile force exerted by the billet withdrawal system will cause rupture of the billet skin as soon as this force exceeds the value RB. If, however, the mould is mounted on springs, sticking causes the mould to move with the billet. The tensile force applied to the billet skin in this case increases gradually, as shown by RS, and is governed by the elastic coefficient of the spring suspension and the speed of the mould movement (assumed during sticking to be the same as that of the billet withdrawal). In Fig. 16 RS is shown for a spring elastic coefficient of 300 lb./in. and a billet withdrawal speed of 24 in./min. This coefficient is within the range 150–500 lb./in., found to be suitable in practice. It is also assumed that the maximum permissible travel of the springs is limited to 2 in., at which point the rate of application of the tensile force to the billet skin rises very rapidly along the line SU. If the sticking force remains at a level of 1000 lb. throughout, then during the time from R to S the applied tensile force is always less than the strength of the billet skin. Furthermore, although the tensile force applied increases rapidly along SU at the end of the spring travel the sticking force XT is now less than the rupturing force XC so that the billet is freed from the mould, and the latter moves upwards to a new position. The time for this upward movement is very much shorter than in reciprocating systems and corresponds to a billet movement of less than 0·1 in. Rupture can and has occurred during this period but the chances are much ess than in other systems.

The particular case described is only one example from a wide range which might be met under practical conditions of continuous casting. The choice of the elastic coefficient of the spring suspension must depend largely on the breaking-strength/time curve of the steel being cast which in turn depends on the type of steel, the shape and size of the cross-section, and the rate of solidification. Moreover, the springs must sustain the combined weight of the mould and cooling water, and at the same time have enough additional flexibility to allow a displacement of up to 2 in. should prolonged sticking occur.

CONCLUSIONS

The work described in this paper has brought out the essential differences between the reciprocating and the spring-mounted mould systems. In the first, any sticking during the period of relative movement of the billet and mould can rupture the skin because of the very rapid rise of stresses, but an adequate safeguard is provided over a wide range of casting speeds against the progressive rupture described earlier. In the second, sticking introduces automatically, and without rupture, a mechanism for strengthening the billet skin to a value where it can withstand the force necessary to strip the billet from the mould wall.[13] Rupture of the billet skin is thus prevented instead of the consequences of rupture merely being circumvented.

Acknowledgments

This paper is based on the work carried out by the Physics Department of B.I.S.R.A. for the Ingots Committee of the Steelmaking Division.

The authors wish to record their indebtedness to the Director of B.I.S.R.A., Sir Charles Goodeve; to the recent Head of the Physics Department, Professor M. W. Thring; to the recent Head of the Steelmaking Division, Dr. A. H. Leckie; and to the individual members of the Ingots Committee for their constant encouragement and advice during the course of this work.

The experimental results are the outcome of the work of many colleagues over the past few years and the authors gratefully acknowledge the contributions of M. P. Newby, B. O. Smith, K. Watkins, E. T. Linacre, E. Leigh, A. Pritchard, and R. J. Garnett. Mr. A. Hambly, Head of the Workshop staff of the B.I.S.R.A. London Laboratories, has also given a great deal of help and advice in the construction and maintenance of the laboratory plant used in this work.

APPENDIX

Calculation of Thickness and Surface Temperature of Billet Skin

In Fig. 17, XY is the axis of a cylindrical mould of radius R and AA' is a disc of liquid steel at the free surface. At a distance l below AA' the disc is at position BB' with a solid skin thickness of x. It is assumed that the temperature of the solid boundary is θ_1, that the liquid steel core is all at temperature θ_1 (where θ_1 is the solidus temperature), and that θ_2 is the temperature of the outer face of the billet skin.

Now, in the solid skin, the temperature θ at radius r, where $R > r > R - x$, is given by[14]:

$$\theta = \theta_1 - \frac{(\theta_1 - \theta_2)}{\log_e(R/R-x)} \log_e \frac{r}{R-X} \quad \ldots\ldots(6)$$

Taking L as the latent heat of fusion, ρ as the density, S as the specific heat, and k as the thermal conductivity, and assuming that these quantities are temperature-independent over the range of temperatures used, the total loss of heat from the elemental disc, of thickness dl, in moving from position AA' to BB' is given by:

$$2\pi R dl[Q] = \pi(2R-x)x dl\,\rho L + 2\pi\rho S dl \int_{R-x}^{R} (\theta_1 - \theta)\,dr$$

where $(\theta_1 - \theta)$ is given by equation (6)

$$[Q] = \int_0^t H dt = \text{total heat lost/sq. cm.}$$

Substituting from equation (6),

$$2\pi R dl[Q] = \pi(2R-x)x dl\rho L + \frac{2\pi\rho S dl(\theta_1 - \theta_2)}{\log_e(R/R-x)}[Y] \quad \ldots\ldots(7)$$

where $[Y] = \frac{1}{2}R^2 \log_e (R/R-x) - \frac{1}{4}(2R-x)x$.

From the experimental data,

$$\left(\frac{dQ}{dt}\right)_{r=R} = (64 - 8\sqrt{t}) \times 2\pi R dl$$

Also, since

$$\left(\frac{dQ}{dt}\right)_R = -k\left(\frac{d\theta}{dr}\right)_R \times 2\pi R dl$$

$$\left(\frac{dQ}{dt}\right)_R = \frac{2\pi k(\theta_1 - \theta_2)}{\log_e(R/R-x)}\,dl = 2\pi R(64 - 8\sqrt{t})dl$$

i.e.,

$$\frac{\theta_1 - \theta_2}{\log_e(R/R-x)} = \frac{RH}{k}$$

where $H = 64 - 8\sqrt{t}$.

The total heat lost/sq. cm. $[Q]$ is equal to $\int_0^t H dt$

i.e.,

$$[Q] = 64t - \frac{16}{3}t^{3/2}$$

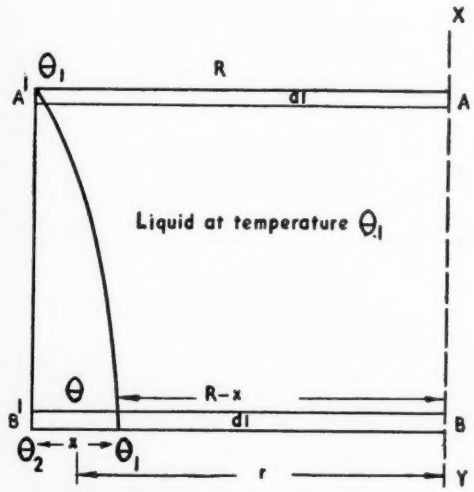

Fig. 17—Thermal conditions assumed during freezing of a continuously cast billet

$$\therefore \frac{RQ}{\rho L} = (2R-x)x + \frac{SHR}{Lk}[Y] \quad \ldots\ldots(8)$$

For small values of x/R

$$[Y] = \tfrac{1}{2}R^2 \log_e (R/R-x) - \tfrac{1}{4}(2R-x)x \simeq \tfrac{1}{2}x^2$$

therefore as a first approximation equation (8) may be written as

$$\frac{RQ}{\rho L} = (2R-x)x + \frac{SHR}{Lk} \times \frac{x^2}{2} \quad \ldots\ldots(9)$$

and this quadratic equation can then be solved to give approximate values of $x - x'$ (say), corresponding to different values of t.

To obtain more accurate values of x, Newton's method of successive approximations may be used. The two sets of values are so close that for practical purposes values of x' can be taken.

The surface temperature of the billet corresponding to the various values of t is given by the relation:

$$\theta_1 - \theta_2 = \frac{RH}{k} \log_e \frac{R}{R-x} \quad \ldots\ldots(10)$$

where θ_1 is the solidus temperature, taken as 1500° C.

By inserting the following numerical values[15] of the thermal constants of steel:

$K = 0{\cdot}07$ cal./cm. sec. °C.
$S = 0{\cdot}16$ cal./g. °C.
$L = 64$ cal./g.
$\rho = 7{\cdot}4$ g./c.c.

and assuming $\theta_1 = 1500°$ C.

then the calculated values of x and θ_2 are shown as functions of time in Figs. 13 and 14, respectively.

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Chromium–Oxygen Equilibrium in Liquid Iron

By E. T. Turkdogan, Ph.D., M.Met.

SYNOPSIS

Iron–chromium melts have been equilibrated with hydrogen–water-vapour mixtures at 1565°, 1600°, and 1660° C., and chromium and oxygen contents in the melt have been determined. Chromium lowers the activity coefficient of dissolved oxygen, but at the concentrations dealt with here, oxygen has no measurable effect on the activity of chromium, which obeys Henry's law up to a concentration of 12% at least.

The results obtained indicate that for the reaction $2Cr(s) + \frac{3}{2}O_2(g) = Cr_2O_3(s)$ the free energy of formation is:

$$\Delta G^\circ_T = -246{,}000 + 48{\cdot}0T \text{ cal. from } 1700^\circ \text{ to } 2100^\circ \text{ K.}$$

and $$\Delta G^\circ_T = -264{,}000 + 59{\cdot}4T \text{ cal. from } 1000^\circ \text{ to } 2100^\circ \text{ K.}$$

The influence of the chromium–oxygen interaction on the deoxidation of steel and the decarburization of iron–chromium–carbon melts is discussed. 964

THE reaction between chromium and oxygen dissolved in iron is of great importance in the manufacture of steels containing chromium, and controlled deoxidation of chromium steels requires a knowledge of the chromium–oxygen interaction. Investigations now in progress into the effect of slag composition on the activity of dissolved chromic oxide cannot be completed unless the concentrations of dissolved chromium and oxygen in equilibrium with pure chromic oxide are known.

The latest work on the study of this reaction was carried out by Chen and Chipman.[1] They reviewed the literature on this matter up to 1947, and earlier work will not be referred to in this paper except where necessary.

Chen and Chipman[1] equilibrated iron–chromium melts with hydrogen–water-vapour mixtures, at 1595° C., in the presence or absence of solid chromic oxide or chromite slags. When there was no slag, the metal samples taken were suitable for analysis for chromium and oxygen but metal samples from melts under solid slags were porous to a varying degree, and, as stated by Chen and Chipman, "microscopic examination showed rather frequent presence of entrapped oxide crust just beneath the surface of the ingot, and it is always possible that some of this material is not removed in grinding the sample in preparation for analysis." On these grounds it is expected that their value of the free energy change in the formation of chromic oxide from its constituent elements may be high.

The purpose of this paper is to evaluate the free energy of formation of chromic oxide from its elements and to measure the degree of interaction between chromium and oxygen dissolved in molten iron.

EXPERIMENTAL DETAILS

The experimental technique was essentially the same as that described recently.[2] The iron–chromium melts, held in recrystallized alumina crucibles, were equilibrated with chromic oxide and hydrogen–water-vapour mixtures to which argon had been added so that the argon/hydrogen ratio was 4 : 1, the gas preheater being maintained at 1600° C. Experiments were conducted at 1565°, 1600°, and 1660° C. In addition some runs were conducted without any slag formation by suitably adjusting the gas composition.

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Dr. Turkdogan is Head of the Physical Chemistry Section of the Chemistry Department of the Association.

Samples, varying in amount from 8 to 14 g., were sound and when examined metallographically showed no oxide inclusions. Chromium determinations were carried out by the Metallurgy (General) Division of B.I.S.R.A. Oxygen contents were determined by vacuum fusion on samples weighing between 2 and 3 g., determinations being in duplicate.

Most of the melts were equilibrated with the gas phase in the presence of chromic oxide slag. To ensure that the molten metal was exposed to the gas phase for rapid establishment of equilibrium, gas and initial metal composition, at a given temperature, were adjusted so that only a small amount of chromic oxide was formed and this floated freely on the surface. The presence or absence of any slag could easily be observed through a glass window situated on the top of the reaction tube.[2]

During sampling of the metal, almost all the slag adhered to the sampling silica tube and it was not possible to separate satisfactorily the chromic oxide from silica for analytical purposes. Nevertheless, the green colour of the slag was sufficient evidence of the presence of chromic oxide. In their work, Chen and Chipman[1] showed very clearly that over Fe–Cr–O melts only two types of slag could be formed, *i.e.*, green chromic oxide or brown chromite. The sampling tube was free of coloration when melts were conducted without slag formation.

EXPERIMENTAL RESULTS

Establishment of Equilibrium

It was stated previously,[2] that the reaction between molten iron and hydrogen–water-vapour mixtures reached equilibrium in about 10 to 15 min. In the presence of a solid slag, as is the case in these experiments, there are three phases to be equilibrated and extra care must therefore be taken to ensure the attainment of equilibrium at the time of sampling. The following procedure was therefore employed.

At a fixed temperature, slag was allowed to form by introducing a little air, and this slag was then removed completely by reducing with pure dry hydrogen. Water vapour was then introduced into the hydrogen to a predetermined proportion. Slag appeared in the form of small islands floating freely on the surface of the molten metal and the experiment was continued for 2 hr. before a metal sample was taken. Melts D2*A*, D5*A*, and F2*A* in Table I provide examples. In a second experiment, the water-vapour–hydrogen mixture was introduced immediately after the formation of a thick slag by oxidation of the metal. During the experiment the initial thick slag was thinned out and after 2 hr. the metal was sampled again. Examples are melts D2*B*, D5*B*, and F2*B* in Table I.

In some experiments, after a sample had been taken, the gas composition was changed, the temperature and the initial metal composition being kept the same. In consequence the chromium and oxygen contents of the iron changed. Table I provides examples in melts E2*A*, E2*B*, E3*A*, and E3*B*. In addition, for a given gas and metal composition, the slag was reduced or re-formed by increasing or decreasing the temperature of the melt, respectively.

From Table I it will be seen that concordant results were obtained from duplicate experiments. This in turn indicates the reversibility of the reaction and the establishment of equilibrium at the time of sampling.

Because the atomic weight of chromium is close to that of iron and the concentration of oxygen is very low, weight percentages are used in representing metal compositions instead of atom fractions.

In melts under chromic oxide and hydrogen–water-vapour, there are three reactions which interrelate if equilibrium is attained amongst the three phases. These reactions will be considered separately.

$H_2 + \underline{O} = H_2O$ Equilibrium

The equilibrium ratio of the reaction

$$H_2(g) + \underline{O} = H_2O(g) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

is represented as

$$K'_1 = \frac{(p_{H_2O})}{(p_{H_2})[O\,\%]} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In all equations, the following symbols will be employed: (s) = solid, (l) = liquid, and (g) = gas;

Table I

EXPERIMENTAL DATA ON CHROMIUM–OXYGEN EQUILIBRIUM IN LIQUID IRON

1	2	3	4	5	6	7	8
Melt	Slag Colour	$\frac{p_{H_2}}{p_{H_2O}}$	[Cr], wt.-%	[O], wt.-%	$\delta^* \pm \times 10^4$	$\log K'_1$	$-\log f_O^{Cr}$
Melts at 1565° C.							
D1*A*	Green	47·90	12·50	0·0323	0·5	−0·199	0·864
D1*B*	,,	47·87	12·30	0·0305	1·0	−0·164	0·829
D2*A*	,,	42·69	10·10	0·0236	2·5	−0·003	0·668
D2*B*	,,	42·66	10·00	0·0235	0·5	−0·001	0·666
D3	No slag	37·07	8·05	0·0231	5·5	0·067	0·598
D4*A*	Green	31·26	6·28	0·0141	...	0·356	0·309
D4*B*	,,	31·26	6·25	0·0147	1·0	0·338	0·327
D5*A*	,,	27·90	5·65	0·0161	1·5	0·347	0·317
D5*B*	,,	27·90	5·60	0·0168	1·0	0·329	0·336
D6	,,	23·72	4·18	0·0131	2·0	0·507	0·157
D7*A*	No slag	27·67	3·20	0·0133	1·5	0·434	0·231
D7*B*	,, ,,	27·67	3·17	0·0118	3·0	0·486	0·179
Melts at 1600° C.							
E1	Green	42·86	12·70	0·0391	2·0	−0·224	0·818
E2*A*	,,	39·31	10·65	0·0320	2·5	−0·100	0·694
E2*B*	,,	38·90	10·05	0·0359	1·0	−0·145	0·739
E3*A*	,,	33·20	8·58	0·0247	4·0	0·086	0·508
E3*B*	No slag	35·00	8·45	0·0316	...	0·044	0·550
E4*A*	Green	27·54	6·55	0·0220	3·5	0·218	0·376
E4*B*	,,	28·32	6·49	0·0204	2·5	0·239	0·355
E5	No slag	40·00	5·70	0·0155	2·0	0·208	0·386
E6*A*	,, ,,	25·88	4·18	0·0154	4·5	0·400	0·194
E6*B*	,, ,,	25·88	4·18	0·0156	0·0	0·394	0·200
Melts at 1660° C.							
F1*A*	Green	27·26	8·69	0·0306	13·0	0·079	0·398
F1*B*	,,	27·26	8·55	0·0322	0·5	0·057	0·420
F2*A*	,,	22·00	6·30	0·0330	5·0	0·139	0·338
F2*B*	,,	22·00	6·30	0·0334	1·0	0·134	0·343
F3	No slag	31·20	6·47	0·0274	0·5	0·068	0·389
F4*A*	,, ,,	33·29	5·85	0·0255	2·5	0·071	0·406
F4*B*	,, ,,	33·29	5·70	0·0217	0·5	0·141	0·336
F5	Brown	24·71	4·20	0·0240	1·0	0·227	0·250
F6	,,	21·89	3·21	0·0236	1·5	0·287	0·190

*The deviation of duplicate oxygen determinations from their mean. Where greater than $2·0 \times 10^{-4}$%, the best duplicate result has been chosen

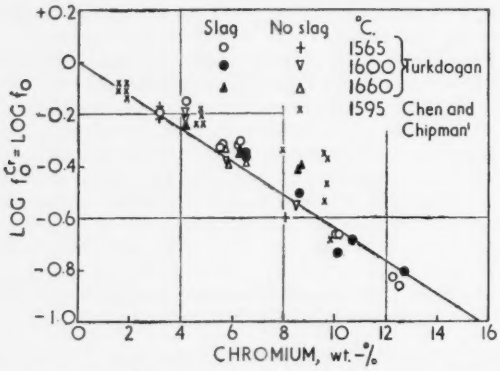

Fig. 1—Log f_O^{Cr} related to chromium content of iron

Cr and O indicate chromium and oxygen in solution in iron. The standard state for gases is 1 atm. at the temperature under consideration, and for chromium and oxygen dissolved in iron the standard state is defined as an infinitely dilute solution, where the activity coefficient is unity.

As may be observed from column 7 in Table I, the value of log K'_1, for a given temperature, is by no means constant, but decreases as the chromium content of iron increases. The reason is obviously that in iron–chromium–oxygen melts the activity coefficient of dissolved oxygen differs from unity.

According to Dastur and Chipman,[3] the free energy change and the equilibrium constant of reaction (1) for pure iron–oxygen melts are:

$$\Delta G^\circ_1 = -32{,}250 + 14{\cdot}50T \text{ cal} \quad \ldots\ldots(3)$$

$$\log K_1 = +\frac{7050}{T} - 3{\cdot}17 \quad \ldots\ldots(4)$$

Because in binary iron–oxygen melts the activity coefficient of oxygen, *i.e.*, f_O^O, is unity up to oxygen saturation, the activity coefficient of oxygen dissolved in iron–chromium melts, *i.e.*, f_O, may be found by the following equation:

$$\log f_O = \log f_O^{Cr} = \log K'_1 - \log K_1 \quad \ldots\ldots(5)$$

The values of $\log f_O^{Cr}$ are listed in Table I.

Figure 1 shows the relationship between $\log f_O^{Cr}$ and chromium content of iron at three temperatures and for melts with and without slag formation. Also included are the results (on melts without slag formation) of Chen and Chipman.[1] There is good agreement between results from melts with and without slag formation. Moreover, within the temperature range studied, the activity coefficient of oxygen appears to be independent of temperature. Although the activity coefficient should be a function of temperature as well as composition in non-ideal solutions, the effect in very dilute solutions, *e.g.*, oxygen in iron, is not readily detectable.

The line in Fig. 1 may be represented by the equation

$$\log f_O = \log f_O^{Cr} = -0{\cdot}064\,[\text{Cr}\%] \quad \ldots\ldots(6)$$

The effect of oxygen on the activity coefficient of chromium in these melts can be calculated from equation (6) by using a relationship derived by Wagner,[4] which in this instance takes the form:

$$\frac{\partial \log f_{Cr}}{\partial [\text{O}\%]} = -0{\cdot}064 \times \frac{52}{16},$$

which on integration gives

$$\log f_{Cr}^O = \log f_{Cr} - \log f_{Cr}^{Cr} = -0{\cdot}208\,[\text{O}\%] \quad \ldots(7)$$

Further details of this calculation are given elsewhere.[2]

$2\underline{Cr} + 3H_2O = Cr_2O_3 + 3H_2$ Equilibrium

The equilibrium constant of the reaction

$$2\underline{Cr} + 3H_2O(g) = Cr_2O_3(s) + 3H_2(g) \quad \ldots\ldots(8)$$

may be written as

$$K_2 = \frac{(p_{H_2})^3}{(p_{H_2O})^3[\text{Cr}\%]^2} \quad \ldots\ldots(9)$$

To illustrate the validity of reaction (8) and equation (9), $\log(p_{H_2}/p_{H_2O})$ is plotted in Fig. 2 against log [Cr%]. A general equation for the three parallel lines may be written as

$$\log \frac{(p_{H_2})}{(p_{H_2O})} = \tfrac{2}{3} \log [\text{Cr}\%] + C \quad \ldots\ldots(10)$$

This is a rearranged form of equation (9), and the constant C, at a given temperature, is equal to $(\log K_2)/3$. The fact that the relationship in Fig. 2 for each temperature is linear, with a correct slope, indicates that the activity of chromium is equal to its concentration, at least up to 12% of chromium, *i.e.*, $f_{Cr} = 1{\cdot}0$. This is to be expected from the similarity of the properties of iron and chromium.

$2\underline{Cr} + 3\underline{O} = Cr_2O_3$ Equilibrium

Combination of equations (1) and (8) gives

$$2\underline{Cr} + 3\underline{O} = Cr_2O_3(s) \quad \ldots\ldots(11)$$

for which the equilibrium constant is

$$K_3 = \frac{1}{[a_{Cr}]^2[a_O]^3} \quad \ldots\ldots(12)$$

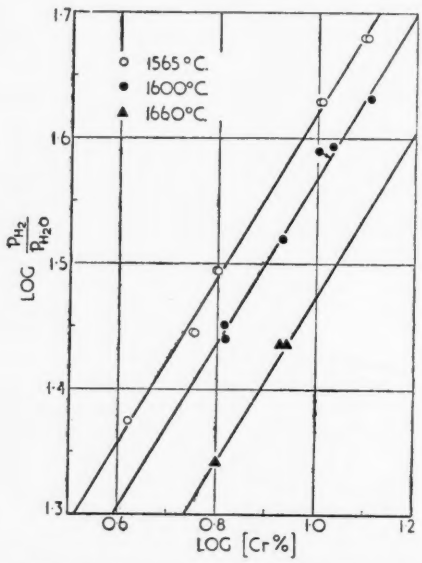

Fig. 2—($H_2 + H_2O$) gas mixtures in equilibrium with chromic oxide and chromium dissolved in iron

where $[a_{Cr}] = [Cr\%]f_{Cr}$

$[a_O] = [O\%]f_O$.

As already pointed out, the value of f_{Cr} is unity within the concentration range studied. The value of f_O, however, may be obtained from Fig. 1 or equation (6).

$Fe + 2\underline{Cr} + 4\underline{O} = FeCr_2O_4$ Equilibrium

Although it was not intended to study this reaction, in the last two experiments, F5 and F6, a brown slag was obtained and in view of the findings of Chen and Chipman[1] this was assumed to be chromite; the following reaction may therefore be written:

$$Fe(l) + 2\underline{Cr} + 4\underline{O} = FeCr_2O_4(s) \quad \ldots\ldots(13)$$

and the equilibrium constant is

$$K_4 = \frac{1}{[a_{Fe}][a_{Cr}]^2[a_O]^4} \quad \ldots\ldots(14)$$

where a_{Fe} is taken as unity because only a small percentage of chromium is present in iron in these melts; the values of a_{Cr} and a_O are obtained as before. The mean values of log K_4 and ΔG°_4 from these two experiments are:

$$\log K_4 = 5{\cdot}98$$
$$\Delta G^\circ_4 = -52{,}880 \text{ cal. at } 1660^\circ \text{ C.} \quad \ldots(15)$$

THERMODYNAMIC CALCULATIONS

$2Cr + \frac{3}{2}O_2 = Cr_2O_3$ Equilibrium

The free-energy-change/temperature relationships for reactions (8) and (11) can easily be found from the data in Table I. It should, however, be pointed out that such a relationship based on three close temperatures, *e.g.*, 1565°, 1600°, and 1660° C., may be subject to error when extrapolated outside the temperature range studied. Accurate free-energy-change/temperature functions may be calculated by considering thermal data together with the equilibrium measurements.

The heat of fusion of chromium[5] is + 3500 cal., and 1900° C. is the melting point.[5, 6] The free energy of fusion then becomes:

$$Cr(s) = Cr(l) \quad \ldots\ldots(16)$$
$$\Delta G^\circ = +3500 - 1{\cdot}61T \quad \ldots\ldots(17)$$

The free energy change in forming the dilute solution[7] is given by

$$Cr(l) = \underline{Cr}[1\%] \quad \ldots\ldots(18)$$
$$\Delta G^\circ = 4{\cdot}575T \log \frac{0{\cdot}5585}{52} = -9{\cdot}01T \quad \ldots\ldots(19)$$

Summation of equations (16) and (18) gives

$$Cr(s) = \underline{Cr}[1\%] \quad \ldots\ldots(20)$$

and its free energy change becomes

$$\Delta G^\circ_5 = +3500 - 10{\cdot}62T \quad \ldots\ldots(21)$$

The free energy of formation of water vapour, *i.e.*,

$$H_2(g) + \tfrac{1}{2}O_2(g) = H_2O(g) \quad \ldots\ldots(22)$$

is calculated from the available data[5]:

$$\Delta G^\circ_6 = -60{,}180 + 13{\cdot}93T \text{ from } 1800^\circ \text{ to } 2100^\circ\text{K.} \quad \ldots(23)$$

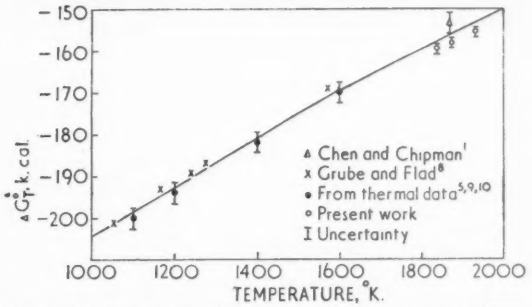

Fig. 3—Free energy of formation of chromic oxide from its elements in their standard states

Combination of equations (8), (20), and (22) gives

$$Cr(s) + \tfrac{3}{2}O_2(g) = Cr_2O_3(s) \quad \ldots\ldots(24)$$

For each experimental melt the value of ΔG°_7 for reaction (24) is calculated from the values of ΔG°_2 derived from the present data, ΔG°_5 from equation (21), and ΔG°_6 from equation (23).

The calculation of the free energy change of reaction (24) may also be based on reaction (11) as follows. Summation of reactions (1) and (22) and their free-energy-change equations will give the following results:

$$\tfrac{1}{2}O_2(g) = \underline{O} \quad \ldots\ldots(25)$$
$$\Delta G^\circ_8 = -27{,}930 - 0{\cdot}57T \text{ from } 1800^\circ \text{ to } 2100^\circ \text{ K.} \quad \ldots(26)$$

Combination of reactions (11), (20), and (25) gives reaction (24), and ΔG°_7 may be evaluated from the values of ΔG°_3 (from experimental results) and ΔG°_5 and ΔG°_8 from equations (21) and (26), respectively.

The mean values of ΔG°_7 obtained by the above calculations are:

Temperature, °C.	ΔG°_7, cal./mole	Uncertainty, ± cal./mole
1565	−159,650	1250
1600	−158,050	1000
1660	−155,530	1000

In Fig. 3, ΔG°_7 is plotted against the absolute temperature; the results of Grube and Flad[8] and Chen and Chipman[1] are also included. According to the National Bureau of Standards,[5] the heat and free energy of formation of chromic oxide are − 269,700 and − 250,200 cal./mole at 298·16° K.; by combination of these values with high-temperature heat-capacity and entropy data given by Kelley,[9, 10] the free energy of formation of chromic oxide from its elements in their standard states can be calculated at various temperatures. The relationship in Fig. 3 is not linear, but slightly curved. For convenience the following equations may be written for two ranges of temperatures:

$$\Delta G^\circ_7 = -246{,}000 + 48{\cdot}0T \text{ from } 1700^\circ \text{ to } 2100^\circ \text{ K.} \quad \ldots(27)$$

and

$$\Delta G^\circ_7 = -264{,}000 + 59{\cdot}4T \text{ from } 1000^\circ \text{ to } 2100^\circ \text{ K.} \quad \ldots(28)$$

$Cr_2O_3 + 3\underline{C} = 2\underline{Cr} + 3CO$ Equilibrium

Dennis and Richardson[11] showed recently the relationship between carbon and chromium contents of iron in equilibrium with chromic oxide. It was found by combining their experimental results with those of Chen and Chipman.[1] In view of the present investigation the above reaction may be reconsidered.

Richardson and Dennis[12] equilibrated carbon-monoxide–carbon-dioxide mixtures with pure iron–carbon melts to study the following reaction:

$$\underline{C} + CO_2(g) = 2CO(g) \quad \ldots\ldots(29)$$

The free energy change of this reaction calculated from their results is:

$$\Delta G^\circ_9 = +34{,}500 - 31{\cdot}07T \quad \ldots\ldots(30)$$

As in the case of chromium and oxygen, the activity of carbon is defined as equalling its weight-percentage concentration in infinitely dilute solutions.

The free energy of reaction

$$CO(g) + \tfrac{1}{2}O_2(g) = CO_2(g) \quad \ldots\ldots(31)$$

is given by Richardson and Jeffes[13] as

$$\Delta G^\circ_{10} = -67{,}550 + 20{\cdot}75T \quad \ldots\ldots(32)$$

Combination of reactions (20), (24), (29), and (31) gives

$$Cr_2O_3(s) + 3\underline{C} = 2\underline{Cr} + 3CO(g) \quad \ldots\ldots(33)$$

and its free energy change is calculated from equations (21), (27), (30), and (32) as

$$\Delta G^\circ_{11} = +153{,}850 - 100{\cdot}2T \quad \ldots\ldots(34)$$

and

$$\log K_{11} = -\frac{33{,}620}{T} + 21{\cdot}9 \quad \ldots\ldots(35)$$

The equilibrium constant of reaction (33) may be written as

$$K_{11} = \frac{(p_{CO})^3[a_{Cr}]^2}{(a_{Cr_2O_3})[a_C]^3}.$$

As already pointed out, the activity of chromium in iron–chromium–oxygen melts is equal to its concentration, and on the assumption that the ideal behaviour of chromium is not affected by small proportions of carbon, the above equation becomes:

$$K_{11} = \frac{[Cr\,\%]^2}{[a_C]^3} \quad \ldots\ldots(36)$$

if the reaction is considered to take place under 1 atm. of carbon monoxide and with a solid chromic oxide slag. Carbon activities (in terms of weight percentages) in iron–chromium–carbon melts can be calculated from the data of Richardson and Dennis.[14]

DISCUSSION

From the viewpoint of steelmaking, the oxidation of chromium may be considered to be controlled by reaction (11), *i.e.*,

$$2\underline{Cr} + 3\underline{O} = Cr_2O_3(s),$$

the free energy change and equilibrium constant of which may be obtained from equations (21), (26), and (27):

$$\Delta G^\circ_3 = -169{,}210 + 70{\cdot}95T \quad \ldots\ldots(37)$$

$$\log K_3 = +\frac{36{,}980}{T} - 15{\cdot}508 \quad \ldots\ldots(38)$$

where

$$K_3 = \frac{1}{[Cr\,\%]^2[a_O]^3} \quad \ldots\ldots(39)$$

From equations (6), (38), and (39) the oxygen content of iron can be predicted for a given concentration of chromium and temperature, when chromic oxide is formed as a result of deoxidation; or alternatively, it is possible to calculate the proportion of chromium required to deoxidize steel, at a given temperature, to a pre-fixed oxygen level. For the sake of convenience, this relationship is presented graphically in Fig. 4 for various temperatures. The lines give the oxygen and chromium contents in equilibrium with chromic oxide. Note that the oxygen–chromium isothermals have definite minima, which for all temperatures lie at about 4·5% of chromium. It therefore follows that, at a given temperature, a maximum deoxidation by chromium can be obtained when its concentration is between 4 and 5%, above which chromium becomes a less effective deoxidizer. The reason is that chromium lowers the activity coefficient of dissolved oxygen to such an extent that the *concentration* of oxygen must increase at the higher chromium contents. Figure 4 shows that in considering deoxidation of steel it is essential to know the magnitude of interaction between oxygen and deoxidizing elements dissolved in iron.

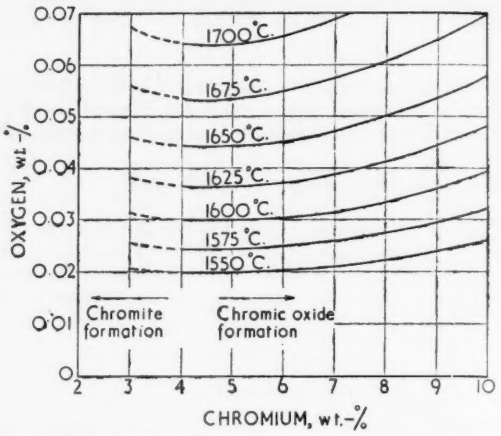

Fig. 4—Relationship between oxygen and chromium dissolved in liquid iron in equilibrium with chromic oxide

At low chromium concentrations chromite forms and therefore the isothermals shown by dotted curves in this region of Fig. 4 refer to metastable chromic oxide as the product of the deoxidation.

The free energy of formation of chromite from liquid iron, chromic oxide, and oxygen is found to be — 49,850 cal./mole at 1660° C., the calculation being based on the values of ΔG°_4 in equation (15), ΔG°_5 in equation (21), ΔG°_8 in equation (26), and ΔG°_7 in equation (27). This is not in good agreement with the value of — 42,500 cal./mole calculated by extrapolation of the free-energy-change/temperature function given by Richardson, Jeffes, and Withers[15] for the reaction

$$Fe(s) + Cr_2O_3(s) + \tfrac{1}{2}O_2(g) = FeCr_2O_4(s) \quad \ldots\ldots(40)$$

The difference of 7350 cal. between these two values may be due to the thermal segregation of gases in the equilibrium measurements of Boericke and Bangert[16] on whose results the free energy change of reaction (40) was calculated by Richardson, Jeffes, and Withers.[15]

The present results are of importance in connection with the decarburization of iron–chromium–carbon melts under a chromic oxide slag, *i.e.*, reaction (33).

In Fig. 5, carbon, wt.-%, is plotted against chromium, wt.-%, for melts in equilibrium with chromic oxide under 1 atm. of carbon monoxide. The isothermals were calculated by means of equations (35) and (36) and the carbon activities were calculated from Richardson and Dennis.[14] The three broken lines were calculated from the results of Hilty.[17]

The significance of the relationship in Fig. 5, from the viewpoint of steelmaking, is that it indicates the limit to which an iron–chromium–carbon melt can be decarburized at 1 atm. of carbon monoxide without the loss of chromium by the formation of chromic oxide.

CONCLUSIONS

Chromium lowers the activity coefficient of dissolved oxygen to an important extent; the magnitude of this interaction is represented by

$$\log f_O^{Cr} = -0{\cdot}064[Cr\%].$$

The reverse effect, *i.e.*, the influence of oxygen on the activity coefficient of chromium, is calculated to be

$$\log f_{Cr}^{O} = -0{\cdot}208[O\%].$$

The linear relationship between log (p_{H_2}/p_{H_2O}) and log [Cr%] (*see* Fig. 2 and equation (10)) indicates that in these melts chromium obeys Henry's law within the composition range covered in the present experiments, *i.e.*, up to 12% of chromium.

Combination of the results of this work together with others obtained from reliable sources, gives the free energy of formation of chromic oxide from its constituent elements in their standard states, *i.e.*,

$$Cr(s) + \tfrac{3}{2}O_2(g) = Cr_2O_3(s)$$

as

$$\Delta G^\circ_7 = -246{,}000 + 48{\cdot}0T \text{ from } 1700^\circ \text{ to } 2100^\circ \text{ K.}$$

The free energy of formation of chromic oxide from chromium and oxygen dissolved in iron, *i.e.*,

$$2\underline{Cr} + 3\underline{O} = Cr_2O_3(s)$$

is given by

$$\Delta G^\circ_3 = -169{,}210 + 70{\cdot}95T$$

and its equilibrium constant is

$$\log K_3 = +\frac{36{,}980}{T} - 15{\cdot}508$$

where

$$K_3 = \frac{1}{[Cr\%]^2[a_O]^3}.$$

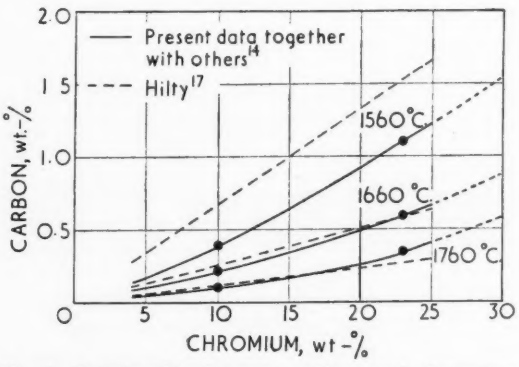

Fig. 5—Relationship between carbon and chromium dissolved in liquid iron in equilibrium with chromic oxide

From these equations, the relationship between oxygen and chromium concentrations dissolved in iron and equilibrated with chromic oxide is shown graphically in Fig. 4. At a fixed temperature, maximum deoxidation occurs with 4·5% of chromium. Note that these diagrams apply to pure iron–chromium–oxygen melts; in more complex systems, appropriate allowance must be made for the effects of other alloying elements on the activities of chromium and oxygen.

Decarburization of iron–chromium–carbon melts, without the loss of chromium, is governed by the reaction

$$Cr_2O_3(s) + 3\underline{C} = 2\underline{Cr} + 3CO(g),$$

the free energy change and the equilibrium constant being

$$\Delta G^\circ_{11} = +153{,}850 - 100{\cdot}2T$$

and

$$\log K_{11} = -\frac{33{,}620}{T} + 21{\cdot}9$$

where

$$\log K_{11} = \frac{[Cr\%]^2}{[a_C]^3}.$$

Acknowledgments

The author wishes to thank Dr. J. Pearson for helpful discussions and Mr. L. S. Davis and Mr. K. Speight for carrying out the oxygen and chromium determinations.

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Richardson and Dennis[12] equilibrated carbon-monoxide–carbon-dioxide mixtures with pure iron–carbon melts to study the following reaction:

$$\underline{C} + CO_2(g) = 2CO(g) \quad \ldots\ldots(29)$$

The free energy change of this reaction calculated from their results is:

$$\Delta G^\circ_9 = +34{,}500 - 31{\cdot}07T \quad \ldots\ldots(30)$$

As in the case of chromium and oxygen, the activity of carbon is defined as equalling its weight-percentage concentration in infinitely dilute solutions.

The free energy of reaction

$$CO(g) + \tfrac{1}{2}O_2(g) = CO_2(g) \quad \ldots\ldots(31)$$

is given by Richardson and Jeffes[13] as

$$\Delta G^\circ_{10} = -67{,}550 + 20{\cdot}75T \quad \ldots\ldots(32)$$

Combination of reactions (20), (24), (29), and (31) gives

$$Cr_2O_3(s) + 3\underline{C} = 2\underline{Cr} + 3CO(g) \quad \ldots\ldots(33)$$

and its free energy change is calculated from equations (21), (27), (30), and (32) as

$$\Delta G^\circ_{11} = +153{,}850 - 100{\cdot}2T \quad \ldots\ldots(34)$$

and

$$\log K_{11} = -\frac{33{,}620}{T} + 21{\cdot}9 \quad \ldots\ldots(35)$$

The equilibrium constant of reaction (33) may be written as

$$K_{11} = \frac{(p_{CO})^3[a_{Cr}]^2}{(a_{Cr_2O_3})[a_C]^3}.$$

As already pointed out, the activity of chromium in iron–chromium–oxygen melts is equal to its concentration, and on the assumption that the ideal behaviour of chromium is not affected by small proportions of carbon, the above equation becomes:

$$K_{11} = \frac{[Cr\,\%]^2}{[a_C]^3} \quad \ldots\ldots(36)$$

if the reaction is considered to take place under 1 atm. of carbon monoxide and with a solid chromic oxide slag. Carbon activities (in terms of weight percentages) in iron–chromium–carbon melts can be calculated from the data of Richardson and Dennis.[14]

DISCUSSION

From the viewpoint of steelmaking, the oxidation of chromium may be considered to be controlled by reaction (11), *i.e.*,

$$2\underline{Cr} + 3\underline{O} = Cr_2O_3(s),$$

the free energy change and equilibrium constant of which may be obtained from equations (21), (26), and (27):

$$\Delta G^\circ_3 = -169{,}210 + 70{\cdot}95T \quad \ldots\ldots(37)$$

$$\log K_3 = +\frac{36{,}980}{T} - 15{\cdot}508 \quad \ldots\ldots(38)$$

where

$$K_3 = \frac{1}{[Cr\,\%]^2[a_O]^3} \quad \ldots\ldots(39)$$

From equations (6), (38), and (39) the oxygen content of iron can be predicted for a given concentration of chromium and temperature, when chromic oxide is formed as a result of deoxidation; or alternatively, it is possible to calculate the proportion of chromium required to deoxidize steel, at a given temperature, to a pre-fixed oxygen level. For the sake of convenience, this relationship is presented graphically in Fig. 4 for various temperatures. The lines give the oxygen and chromium contents in equilibrium with chromic oxide. Note that the oxygen–chromium isothermals have definite minima, which for all temperatures lie at about 4·5% of chromium. It therefore follows that, at a given temperature, a maximum deoxidation by chromium can be obtained when its concentration is between 4 and 5%, above which chromium becomes a less effective deoxidizer. The reason is that chromium lowers the activity coefficient of dissolved oxygen to such an extent that the *concentration* of oxygen must increase at the higher chromium contents. Figure 4 shows that in considering deoxidation of steel it is essential to know the magnitude of interaction between oxygen and deoxidizing elements dissolved in iron.

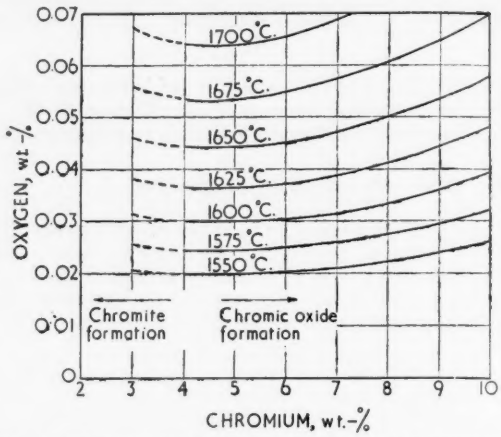

Fig. 4—Relationship between oxygen and chromium dissolved in liquid iron in equilibrium with chromic oxide

At low chromium concentrations chromite forms and therefore the isothermals shown by dotted curves in this region of Fig. 4 refer to metastable chromic oxide as the product of the deoxidation.

The free energy of formation of chromite from liquid iron, chromic oxide, and oxygen is found to be — 49,850 cal./mole at 1660° C., the calculation being based on the values of ΔG°_4 in equation (15), ΔG°_5 in equation (21), ΔG°_8 in equation (26), and ΔG°_7 in equation (27). This is not in good agreement with the value of — 42,500 cal./mole calculated by extrapolation of the free-energy-change/temperature function given by Richardson, Jeffes, and Withers[15] for the reaction

$$Fe(s) + Cr_2O_3(s) + \tfrac{1}{2}O_2(g) = FeCr_2O_4(s) \quad \ldots\ldots(40)$$

The difference of 7350 cal. between these two values may be due to the thermal segregation of gases in the equilibrium measurements of Boericke and Bangert[16] on whose results the free energy change of reaction (40) was calculated by Richardson, Jeffes, and Withers.[15]

The present results are of importance in connection with the decarburization of iron–chromium–carbon melts under a chromic oxide slag, *i.e.*, reaction (33).

In Fig. 5, carbon, wt.-%, is plotted against chromium, wt.-%, for melts in equilibrium with chromic oxide under 1 atm. of carbon monoxide. The isothermals were calculated by means of equations (35) and (36) and the carbon activities were calculated from Richardson and Dennis.[14] The three broken lines were calculated from the results of Hilty.[17]

The significance of the relationship in Fig. 5, from the viewpoint of steelmaking, is that it indicates the limit to which an iron–chromium–carbon melt can be decarburized at 1 atm. of carbon monoxide without the loss of chromium by the formation of chromic oxide.

CONCLUSIONS

Chromium lowers the activity coefficient of dissolved oxygen to an important extent; the magnitude of this interaction is represented by

$$\log f_O^{Cr} = -0{\cdot}064[Cr\%].$$

The reverse effect, *i.e.*, the influence of oxygen on the activity coefficient of chromium, is calculated to be

$$\log f_{Cr}^{O} = -0{\cdot}208[O\%].$$

The linear relationship between log (p_{H_2}/p_{H_2O}) and log [Cr%] (*see* Fig. 2 and equation (10)) indicates that in these melts chromium obeys Henry's law within the composition range covered in the present experiments, *i.e.*, up to 12% of chromium.

Combination of the results of this work together with others obtained from reliable sources, gives the free energy of formation of chromic oxide from its constituent elements in their standard states, *i.e.*,

$$Cr(s) + \tfrac{3}{2}O_2(g) = Cr_2O_3(s)$$

as

$$\Delta G°_7 = -246{,}000 + 48{\cdot}0T \text{ from } 1700° \text{ to } 2100° \text{ K.}$$

The free energy of formation of chromic oxide from chromium and oxygen dissolved in iron, *i.e.*,

$$2\underline{Cr} + 3\underline{O} = Cr_2O_3(s)$$

is given by

$$\Delta G°_3 = -169{,}210 + 70{\cdot}95T$$

and its equilibrium constant is

$$\log K_3 = +\frac{36{,}980}{T} - 15{\cdot}508$$

where

$$K_3 = \frac{1}{[Cr\%]^2[a_O]^3}.$$

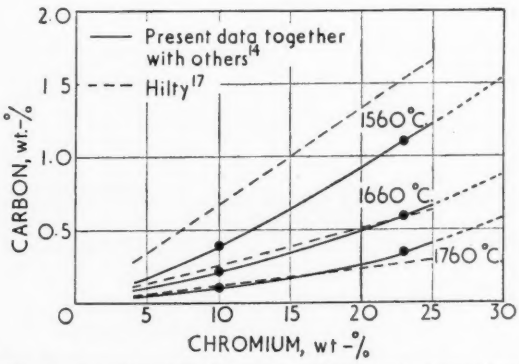

Fig. 5—Relationship between carbon and chromium dissolved in liquid iron in equilibrium with chromic oxide

From these equations, the relationship between oxygen and chromium concentrations dissolved in iron and equilibrated with chromic oxide is shown graphically in Fig. 4. At a fixed temperature, maximum deoxidation occurs with 4·5% of chromium. Note that these diagrams apply to pure iron–chromium–oxygen melts; in more complex systems, appropriate allowance must be made for the effects of other alloying elements on the activities of chromium and oxygen.

Decarburization of iron–chromium–carbon melts, without the loss of chromium, is governed by the reaction

$$Cr_2O_3(s) + 3\underline{C} = 2\underline{Cr} + 3CO(g),$$

the free energy change and the equilibrium constant being

$$\Delta G°_{11} = +153{,}850 - 100{\cdot}2T$$

and

$$\log K_{11} = -\frac{33{,}620}{T} + 21{\cdot}9$$

where

$$\log K_{11} = \frac{[Cr\%]^2}{[a_C]^3}.$$

Acknowledgments

The author wishes to thank Dr. J. Pearson for helpful discussions and Mr. L. S. Davis and Mr. K. Speight for carrying out the oxygen and chromium determinations.

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A Statistical Study of the Creep and Fatigue Properties of a Precision-Cast High-Temperature Alloy

By G. T. Harris, M.A., F.Inst.P., F.I.M., and H. C. Child, B.Sc., A.I.M.

SYNOPSIS

The average mechanical properties at room temperature, the creep strength at 700–850° C., and the fatigue strength at 700–870° C. have been evaluated for precision-cast G.34, a cobalt-base alloy developed for gas-turbine rotor blades. A quality control study of the rupture strength of G.34 castings has shown that the precision-casting process can be used to give consistent properties in that no greater scatter in properties need be expected from heat to heat than within one heat.

The scatter of the 300-hr. rupture strength and the endurance strength (40×10^6 reversals) at 750° C. has been shown to be $\pm$ 10% and $\pm$ 22% ($\pm 2\sigma$). The practical implication of these results is that the average values of the high-temperature properties must be reduced by about 15% in the case of applications where creep is the limiting factor and by about 30% where fatigue is of major importance.

For an alloy of this type, fatigue is probably of major importance at temperatures up to about 800° C., whilst creep is more important above this range. Accordingly, best use can be made of this cast material above 800° C., and it is above this temperature that the properties become attractive in comparison with existing wrought materials. At these higher temperatures the scatter in properties is also smaller. 946

Introduction

THE demand for better high-temperature materials for use as stator and rotor blades in gas turbines has led to considerable research to develop improved forged alloys. As the high-temperature strength of these alloys has been raised, the forgeability has inevitably been lowered, with consequent serious production difficulties.

For this reason, considerable use has been made in the U.S.A. of turbine blades cast by the lost-wax process. In the U.K., the difficulty of ensuring that blades made by this process are free from defects and have mechanical properties typical of the material has led to very little use being made of this method of fabrication. Such use as has been made has been confined to stator blades, where the static stressing is lower and thermal fatigue rather than mechanical fatigue is the limiting factor.

The alloy most commonly used in America was Vitallium. The scatter in rupture properties of this cobalt-base alloy has been described by Grant.[1] The 100-hr. rupture strength at 815° C. varies from 6·7 to 9·8 tons/sq. in.; *i.e.*, there is a scatter of $\pm$ 19% about the mean rupture strength. Similarly, the 1000-hr. rupture strength varies from 4·0 to 7·1 tons/sq. in., a scatter of $\pm$ 28% about the mean rupture strength.

Grant has shown the important rôle played by the grain size and grain orientation in controlling the rupture strength. In the lost-wax process these properties are controlled by means of the metal casting temperature, the mould temperature, and the rate of cooling of the casting. Reproducibility of properties is stated by Grant to be a function of chemical composition. In particular, high carbon in Vitallium-type alloys was stated to lower the scatter in rupture strength.

Many variants of the original Vitallium alloy were developed in the U.S.A., most of which had better rupture strengths and some of which presumably had less scatter in rupture strength, but, nevertheless, casting materials are being superseded by forged alloys for rotor blades. This is presumably because the higher demands of stress and temperature in the current American engines now renders cast materials

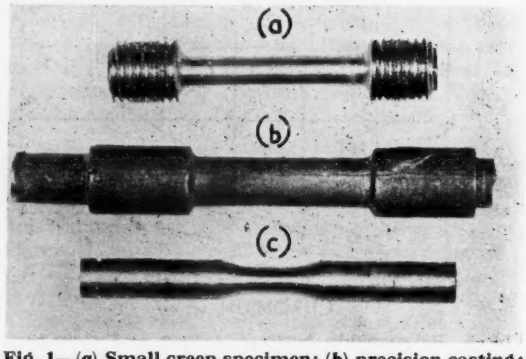

Fig. 1—(*a*) Small creep specimen; (*b*) precision casting; (*c*) hot fatigue specimen

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Mr. Child is Senior Research Metallurgist in the Research Department of William Jessop and Sons, Ltd., of which Mr. Harris is Research Director.

Table I
RESULTS OF SMALL CREEP TESTS

Nest	Specimen	Stress, tons/sq. in.	Temp., °C.	Time, hr., to:			Minimum Creep Rate, × 10⁴ per hr.	Elongation, %	Larson and Miller Parameter $T(20 + \log t)$
				1%	2%	Fracture			
BHG1	*ALAN*	26	700	1	6	27	140	7	20·85
BHG1	*ALAM*	23	,,	1	6	12	...	7	20·51
BHG1	*ALAO*	23	,,	8	24	66	12	6	21·23
BFR3	*AJHC*	20	,,	24	230	586	2·6	6	22·16
BFR2	*AJHB*	17	,,	120	1800	3200	0·6	7	22·88
BHG2	*ALAP*	19	750	2	14	43	62	7	22·13
BFR4	*AJHE*	17	,,	12	70	141	14	7	22·66
BFR5	*AJHF*	17	,,	16	140	309	8	7	23·01
Statistical study		15	,,	...	193	385	6·5	7·0	23·104
BHG1	*ALAK*	13	,,	160	1080	2099	0·8	11	23·56
BFT4	*AJGZ*	14	800	2	7	25	160	8	22·96
BFT1	*AJGW*	12	,,	13	25	91	45	8	23·56
BFT2	*AJGX*	12	,,	9	50	187	24	10	23·90
BHG7	*ALBG*	11	,,	80	220	445	7·2	8	24·30
BFR3	*AJHD*	10	,,	460	820	1137	1·8	6	24·73
BHG2	*ALAQ*	10	850	10	40	112	37	...	24·76
BFT5	*AJHA*	9	,,	33	98	140	15	7	24·91
BFT3	*AJGY*	8	,,	93	230	424	6·4	8	25·41
BHG2	*ALAR*	7	,,	150	580	1468	1·96	14	26·02

unsuitable, owing to their scatter in mechanical properties.

Several years ago the authors' company developed a forged cobalt-base material for turbine blades[2] known as G.32. Initial tests on this material in the precision-cast form showed it to have interesting high-temperature properties but to exhibit considerable scatter in strength. After much development, a high-carbon variation of this alloy known as G.34 was found to have improved creep strength and less scatter in properties. Alloy G.34 has the following nominal composition:

C, %	Mn, %	Si, %	Ni, %	Co, %
0·8	1·0	0·5	12·0	45·0
Cr, %	**V, %**	**Mo, %**	**Nb, %**	**Fe, %**
20·0	2·8	2·0	1·2	15·0

This alloy did not represent the optimum creep strength which could be obtained with alloys of this type. Higher additions of carbon, molybdenum, vanadium, and niobium gave improved creep and fatigue properties at high temperatures, but the resulting room-temperature ductility was too low (less than 1%) for practical use.

This investigation therefore deals with a statistical study of the creep and fatigue properties of G.34, which may be regarded as typical of a precision-cast high-temperature alloy developed especially for gas-turbine blading.

PROCEDURE

In view of the difficulty of casting threaded creep specimens and fatigue specimens with no warpage, it was decided that the investigation would be carried out on specimens machined from small test bars. These test bars were designed to be as close as possible

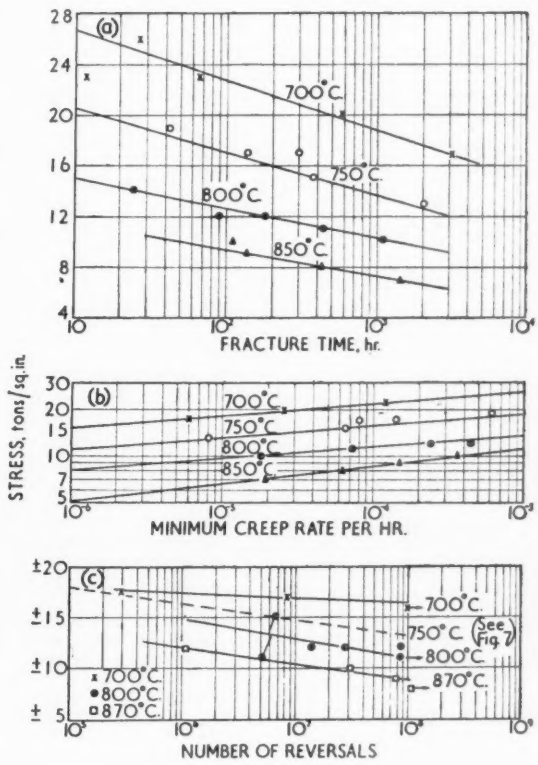

Fig. 2—(*a*) Rupture strength, (*b*) creep strength, and (*c*) fatigue strength of precision-cast G.34

Table II

RESULTS OF SMALL CREEP TESTS AT 15 TONS/SQ. IN. AT 750° C. ON CAST G.34

Nest	Paired Sample Number	Specimen	Time, hr., to:			Minimum Creep Rate, $\times 10^5$ per hr.	Elongation, %
			1%	2%	Fracture		
BCB6	1	*ADND*	26	290	543	3·0	6
BCB6	1	*ADNE*	50	290	492	3·4	3
BCB6	2	*ADNF*	...	...	490	...	...
BCB6	2	*ADNG*	144	160	167	4·0	4
BCC4	3	*ADNM*	25	250	400	4·4	4
BCC4	3	*ADNJ*	18	150	400	5·0	5
BCC4	4	*ADNK*	18	160	167	5·8	3
BCC4	4	*ADNL*	60	300	378	3·8	4
BFT1	5	*AHOW*	8	65	209	14	...
BFT1	5	*AHOX*	20	80	185	17	5
BFT2	6	*AHOZ*	12	117	495	9·0	12
BFT2	6	*AHPA*	40	155	251	7·0	5
BFT3	7	*AHPE*	80	117	118	3·0	3
BFT3	7	*AHPD*	14	270	613	4·0	7
BFT4	8	*AHPF*	14	80	270	12	8
BFT4	8	*AHPG*	20	115	282	10	6
BFT5	9	*AHPJ*	20	170	364	6·0	5
BFT5	9	*AHPK*	37	153	260	8·0	4
BFT6	10	*AHPM*	17	105	345	11	9
BFT6	10	*AHPN*	20	330	451	2·0	3
BFR2	11	*AHPP*	90	330	730	4·0	11
BFR2	11	*AHPQ*	32	330	677	2·0	9
BFR3	12	*AHPS*	60	540	1083	2·0	7
BFR3	12	*AHPT*	20	105	155	12	4
BFR4	13	*AHPV*	45	380	785	2·0	...
BFR4	13	*AHPW*	85	310	581	4·0	7
BFR5	...	*AHPY*	115	480	927	2·0	8
BFR5	...	*AHPZ**	Cold shut		0	...	0
BFV1	14	*AHQB*	14	200	647	4·0	...
BFV1	14	*AHQC*	40	310	627	3·0	10
BFV2	15	*AHQD*	45	265	427	4·0	...
BFV2	15	*AHQF*	55	390	735	3·0	8
BHG4	16	*ALAT*	50	330	764	2·8	10
BHG4	16	*ALAU*	35	180	382	6·8	9
BHG4	...	*ALAV*	40	125	143	12	4
BHG5	17	*ALAW*	45	220	337	5·4	4
BHG5	17	*ALAX*	...	...	439	7·0	8
BHG5	...	*ALAY*	30	95	218	16	8
BHG6	18	*ALAZ*	18	155	416	6·2	9
BHG6	18	*ALBA*	25	145	280	8·0	10
BHG6	19	*ALBB*	20	72	204	20	10
BHG6	19	*ALBC*	10	85	280	12	12
BHG7	20	*ALBD*	25	205	403	5·4	7
BHG7	20	*ALBF*	40	200	361	5·8	7
BHG7	...	*ALBH*	80	310	726	3·2	10
BHG8		*ALBK*	15	145	281	5·5	9
BHG3		*ALBM*	160	540	834	2·2	8

* Cold shut: this result not included in statistical investigation

to the size of the finished small creep and hot fatigue specimens which were to be used. Figure 1 shows the test bar and the creep and fatigue specimens.

Several dozen test bars of this type were cast by the de Havilland Aircraft Co., Ltd., by the lost-wax process. The moulds used cast several test bars in a cluster from one central feeder. A metal-pouring temperature of 1500° C. and a mould temperature of 1000° C. were used throughout. A high percentage of the castings were examined radiographically before machining. The several unsound specimens detected were tested in the normal way to evaluate the effect of the defects.

A series of tests were carried out in small creep units[3] at 700°, 750°, 800°, and 850° C. to evaluate the creep strength of the material. In addition, to check the reproducibility of the material a further 47 specimens were tested at 15 tons/sq. in. at 750° C.

The hot fatigue tests were carried out at approx. 5000 r.p.m. in Wöhler-type units[4] at 700°, 750°, 800°, and 870° C. Again a series of tests (23) were carried out at ± 15 tons/sq. in. at 750° C. to evaluate the reproducibility of the fatigue properties.

Several tensile tests at room temperature were carried out in a Hounsfield tensometer.

RESULTS

The results of the creep tests at various stresses and temperatures are reported in Table I, with the rupture and minimum creep rate results shown graphically in Figs. 2*a* and *b*, respectively. The corresponding fatigue results are shown in Fig. 2*c*. The results of the statistical study of creep and fatigue properties at 15 and ± 15 tons/sq. in. are given in Tables II and III, respectively.

The lines drawn in Fig. 2 are visual estimates of the average values of the properties in question. Where the average values were accurately known (*i.e.*, at 15 tons/sq. in.) at 750° C., the graphs have been drawn through these points with a slope estimated from the remaining points.

The Hounsfield tensometer results are given in Table IV.

Table III

RESULTS OF HOT WÖHLER FATIGUE TESTS AT ± 15 TONS/SQ. IN. AT 750° C. ON CAST G.34

Specimen	Nest No.	Endurance, cycles	Remarks*
JBAD/17	*DCU* 10	28,381,000	
JBAD/18	*DCU* 10	177,100	
JBAD/19	*DCU* 11	61,800	
JBAD/20	*DCU* 11	2,084,300	
JBAD/21	*DCU* 11	102,850,800	U.F.
JBAD/22	*DCU* 11	105,469,400	U.F.
JBAD/23	*DCU* 12	8,185,900	
JBAD/24	*DCU* 12	14,988,600	
JBAD/25	*DCU* 12	60,500	
JBAD/26	*DCU* 12	27,230,800	
JBAD/27	*DCU* 12	19,129,600	
JBAD/28	*DCU* 12	100,000,000	U.F.
JBAD/29	*DCU* 7	841,700	
JBAD/30	*DCU* 7	64,452,200	
JBAD/31	*DCU* 7	627,000	
JBAD/32	*DCU* 7	31,102,300	
JBAD/33	*DCU* 7	2,712,500	
JBAD/34	*DCU* 7	12,879,300	
JBAD/35	*DCU* 13	47,300	
JBAD/36	*DCU* 13	6,690,600	
AHQG	*BFU* 2	4,584,800	
AHQA	*BFR* 5	15,982,300	
AHPB	*BFT* 2	113,122,900	U.F.

* U.F. indicates that the specimen was unfractured at the indicated number of reversals

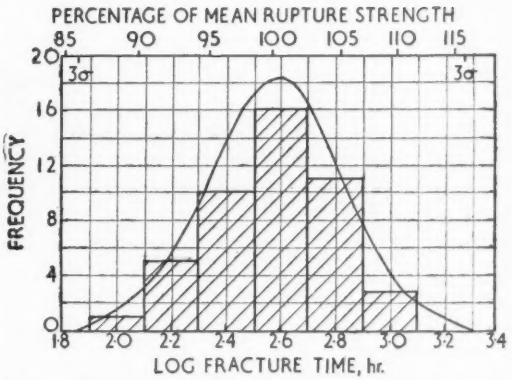

Fig. 3—Frequency histogram for log fracture time at 15 tons/sq. in. at 750° C.

DISCUSSION OF RESULTS

Creep

In the statistical study of creep tests at 15 tons/sq. in. at 750° C., all except three of the 34 specimens radiographed were satisfactory. Two of these unsound specimens gave average creep results, whilst the third (*AHPZ*) fractured on loading, the fracture showing evidence of a large cold shut. The results of *AHPZ* are consequently not included in the statistical study.

For most materials at constant temperature the logarithm of the fracture time has an approximately linear relationship with stress, at least over small ranges of stress values. For G.34 this relationship is true within experimental accuracy over the time range 10–3000 hr. (*see* Fig. 2*a*). The log fracture time may consequently be regarded as varying directly as the rupture strength. Figure 3 is a frequency histogram showing the number of castings having a log fracture time within various ranges; the distribution is essentially normal (Gaussian). The frequency curve calculated from the individual results assuming a Gaussian distribution is also shown in this diagram.

The following statistical parameters:

(i) Mean
(ii) Standard deviation
(iii) Standard error of the mean

have been calculated from Table II for the log fracture time, log time for 2% creep strain, log minimum creep

Table IV

RESULTS OF HOUNSFIELD TENSOMETER TENSILE TESTS AT ROOM TEMPERATURE

Nest No.	Specimen	Maximum Stress, tons/sq. in.	Elongation on $L = 4\sqrt{A}$, %
*BFR*4	*AHPX*	42	2
*BFR*2	*AHPR*	43½	3
*BFV*1	*AHQP*	40	2
*BFT*1	*AHOV*	39½	2½
*BFT*5	*AHPL*	42	2½
*BFT*3	*AHPE*	43½	4½
Mean		42	2½

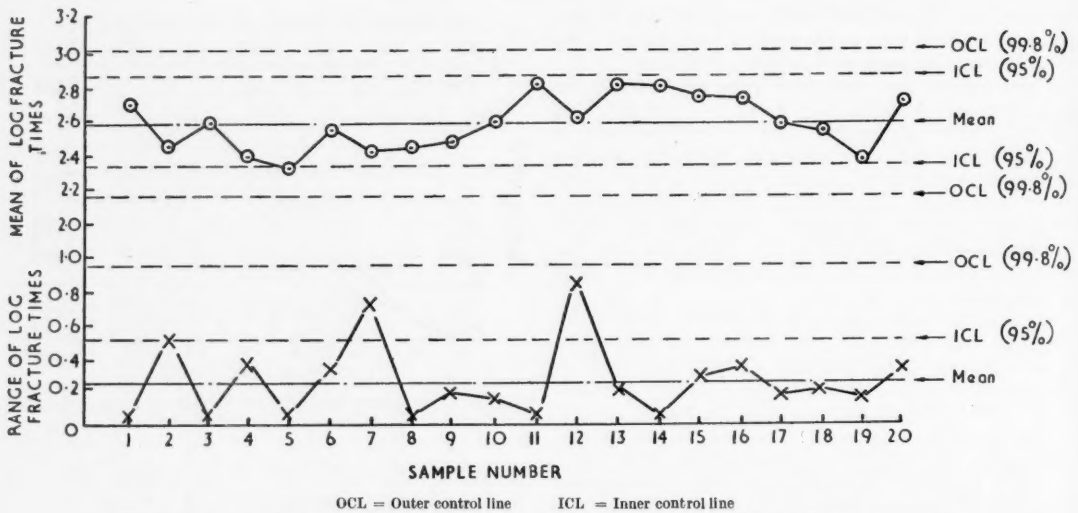

Fig. 4—Control chart for log fracture times at 15 tons/sq. in. at 750° C. of paired samples

rate, and elongation at fracture. These values are shown in Table V.

The statistical parameters of the log fracture time results imply, assuming normal distribution, that 95% of the castings will have lives of 130–1140 hr. and 99·8% of 75–1960 hr. when tested at 15 tons/sq. in. at 750° C., with a mean value of 385 hr.

From the known slope of the stress/log-fracture-time plot (Fig. 2*a*) it can be estimated that the rupture strength of 95% of the castings will lie within ± 10% of the mean value and 99·8% within ± 15% (*see* Fig. 3).

Although no statistical work has been carried out on the accuracy to be expected from the small creep units used, experience would indicate that 99·8% of all tests would lie within ± 5% of the mean results for a perfectly homogeneous material. This estimate of the accuracy may be overcautious, but it does indicate that the scatter obtained with these castings is entirely a function of the material and not of the testing unit used, as these atter (3σ) due to material alone would be $\pm (\sqrt{15^2 - 5^2}) = \pm 14\%$.

It might be expected that there would be more variability in rupture strength between castings from different nests (*i.e.*, heats) than between castings from the same nest. To check this, the results in Table II have been treated as follows. The log fracture time results of pairs (samples) of castings from the same nest have been selected at random, 20 such samples being available. Figure 4 shows the mean and the range of the log fracture time of these paired samples. Also shown in this diagram are the mean log fracture time, the mean range, and the inner and outer control lines based on 95% and 99·8% significance levels, respectively. The standard quality control technique used in British Standard 600R: 1942 has been used.

Both the mean and the range of the log fracture times of the paired samples are in control; 10% (2 in 20) of the range of log fracture times lie outside the 95% control line instead of 5%, but this is not significant. It can be said, therefore, that the variability between nests is in line with the variability within nests. This result is of considerable practical importance, as it demonstrates that satisfactory control of the production of such castings on a commercial basis is possible.

In view of the current interest which has been expressed in the Larson and Miller parameter,[5] it was decided to study the results of the tests at the other stresses and temperatures by this means. Larson and Miller claim that, under creep conditions,

$$T(C + \log t) = P,$$

where T = Absolute temperature of test, ° K.
t = Fracture time, hr.
C = A constant (usually 20)
P = A parameter, constant at constant stress S.

Furthermore, the plot of P *vs.* $\log S$ has been shown in many (but not all) cases to be a straight line. For all the materials studied by Larson and Miller, 20 proved to be a suitable value for C, and so that value has been used here.

Table V

CALCULATED STATISTICAL PARAMETERS FOR PRECISION-CAST G.34

At 15 tons/sq. in. at 750° C.

Parameter	Mean	No. of Observations*	Standard Deviation	Standard Error of Mean
Log fracture time, hr.	2·585	46	0·236	0·038
Log time for 2% creep strain, hr.	2·285	44	0·239	0·036
Log minimum creep rate, $\times 10^5$ per hr.	0·812	45	0·280	0·042
Elongation, %	6·95	40	2·69	0·42

* Complete creep data are not available for all 46 specimens under consideration

Using all the creep results except those at 15 tons/sq. in. at 750° C., the relationship between $\log S$ and $T\ (20 + \log t)$ has been studied. The correlation coefficient r between these two variables was found to be 0·983 which, with the number of samples n being 18, indicates significance on a considerably lower level than 0·1%, *i.e.*, a high correlation between the two variables. It is thus possible to assume a linear relationship.

The equation of the regression line of $T\ (20 + \log t)$ upon $\log S$ was calculated to be

$$T(20 + \log T) \times 10^{-3} = 33{\cdot}79 - 9{\cdot}172 \log S.$$

These results are shown graphically in Fig. 5. Accordingly, when $S = 15$ tons/sq. in.,

$$T(20 + \log t) = 23{\cdot}01 \times 10^3.$$

This may be compared with the mean value of this parameter calculated from the 46 tests at 15 tons/sq. in. at 750° C., which gave a value of $23{\cdot}10 \times 10^3$. Application of the 't test' indicates that there is no significant difference between these values. This shows that the batch of specimens used for the tests at 700–850° C. have the same characteristics as those tested at 15 tons/sq. in. at 750° C.

Thus, by testing an alloy such as G.34 at various stresses and temperatures and applying the Larson and Miller technique, the scatter of the rupture strength, as well as its dependence on time and temperature, can be determined with the minimum of testing.

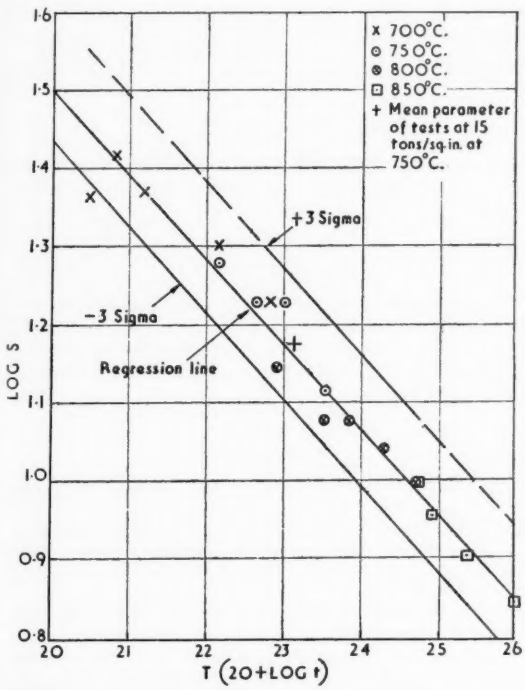

Fig. 5—Correlation of the Larson and Miller parameter and the logarithm of the stress

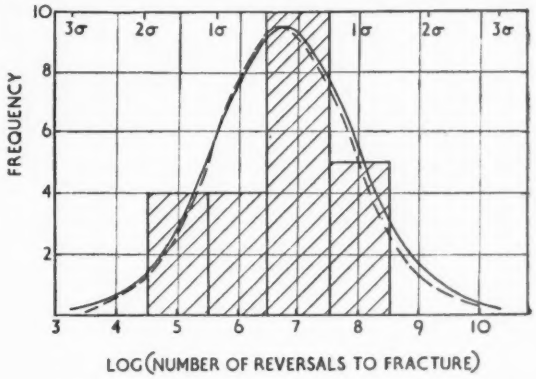

Fig. 6—Frequency histogram for log reversals to fracture at ± 15 tons/sq. in. at 750° C.

The possibility that the strength of castings will show less scatter at higher temperatures has been known from experience with G.34 and other materials. It is attributed to the fact that any small defect, stress raiser, or porosity will have a much more pronounced effect at higher stresses and low temperatures, where the materials are less plastic, than under the more plastic conditions of low stresses and high temperatures.

The standard deviation of the tests at different temperatures have been calculated from Fig. 5 with the results shown in Table VI. Application of the Fisher test to these results shows that only on a 20% level of significance is the standard deviation at 850° C. significantly lower than that of these tests at 700° C. While these results cannot therefore be regarded as statistically significant, they do show the expected trend of decreasing scatter with increasing temperature.

Fatigue

The results of the 23 fatigue tests carried out at ± 15 tons/sq. in. at 750° C. given in Table III have been treated in the following way. The logarithm of the reversals to fracture has been considered to be proportional to the endurance strength of the specimens. Figure 6 is a histogram of the results, which shows that the distribution is essentially normal. Four specimens which did not fracture after 100 million reversals were, as a first approximation, considered as fracturing at the number of reversals at which the test was discontinued. The mean log reversals and the standard deviation were calculated with the following results:

Mean log reversals	6·76
Standard deviation	1·09

The broken line in Fig. 6 represents the Gaussian distribution of such a system.

Considering this distribution, the average log reversals at which four out of 23 samples (unfractured at 100 million) would each be expected to fail was estimated to be 8·35. The mean and standard deviation of the results were then recalculated using this

Table VI

EFFECT OF TEMPERATURE ON SCATTER OF RUPTURE STRENGTH

Test Temperature, °C.	No. of Tests	Standard Deviation of Parameter $T(20 \times \log t) \times 10^{-3}$
700	5	0·46
750*	4	0·3
800	5	0·24
850	4	0·14
750†	46	0·24

* Excludes tests at 15 tons/sq. in.
† Tests at 15 tons/sq. in.

value for the four specimens. The full line in Fig. 6 represents such a Gaussian distribution:

Recalculated mean log reversals	6·81
Recalculated standard deviation	1·17

The other fatigue results at above $\pm$ 15 tons/sq. in. at 750° C. were next studied to determine the slope of the plot of the stress S and the log reversals to fracture. Results at lower than $\pm$ 15 tons/sq. in. were omitted owing to the difficulty of handling results of specimens which did not fracture. The correlation coefficient r was found to be 0·77, and, as the number of samples n was 8, the significance of the linear relationship is at the 2% level. The equation of the regression line of log reversals to fracture upon stress was calculated to be

$$\log R = 17{\cdot}16 - 0{\cdot}65\,S$$

where R = Reversals to fracture.

This gives a value of log R equal to 7·41 when $S = \pm$ 15 tons/sq. in. This may be shown by the 't test' not to be significantly different from the value of 6·84 determined from the 23 tests at $\pm$ 15 tons/sq. in. at 750° C.

Figure 7 shows this regression line and the experimental points. A line parallel to this regression line but drawn through the mean of the 23 tests is also shown, together with the corresponding $\pm 2\sigma$ and $\pm 3\sigma$ lines.

Before considering the scatter of these results in terms of stress it is necessary to consider the scatter due to the testing units themselves. Examination of results on wrought bars of heat-resisting alloys indicates that the scatter (2σ) in terms of stress is $\pm$ 18%. Such materials in the form of heat-treated small-diameter bar should have uniform properties, so that most of this scatter can be attributed to the machines.

At the endurance limit (40×10^6 reversals), the scatter in strength of the G.34 castings is approx. $\pm$ 29% (2σ), so that the scatter due to the inhomogeniety of the castings is approximately $\pm\sqrt{(29^2 - 18^2)} = \pm$ 22%. This value of the scatter of the fatigue strength ($2\sigma = 22\%$) should be compared with the scatter of the rupture strength ($2\sigma = 10\%$). The question arises of what significance to attribute to this result; *i.e.*, does the fatigue strength of castings have an inherently greater scatter than the rupture strength, or has the mode of testing given a false picture ?

No definite answer can be given to this question, but it is known that factors exist in fatigue testing by the Wöhler method which would lead to greater

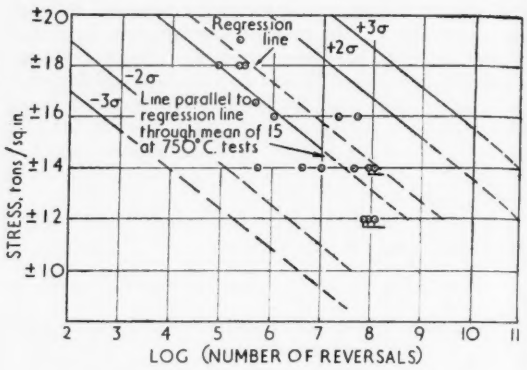

Fig. 7—Fatigue strength of G.34 at 750° C.

scatter in strength with a relatively brittle material of high elastic limit like G.34 than with the more ductile wrought materials. Any misalignment of the shackles, resonance vibrations in the machine, etc., would probably have a more adverse effect on the G.34-type materials. In this connection it is important to note that the 'average value of the fatigue strength' shown in Fig. 2*c* is probably a conservative value, in that most of the errors present in fatigue testing will tend to lower the fatigue limit from the theoretical value.

Since these fatigue tests were carried out, an effort has been made to improve the method of fatigue testing with particular reference to the avoidance of resonance vibrations in the machine and more accurate temperature measurements, with the result that current tests on wrought bar show less than $\pm$ 10% scatter.

Tensile Properties

As shown in Table IV, G.34 has a mean maximum stress of 42 tons/sq. in. and a minimum elongation of 2%.

Acknowledgments

The authors wish to record their thanks to the de Havilland Aircraft Co., Ltd., who cast the small test bars by the lost-wax process, and to Mr. G. Sturgeon and Mr. B. Collier, who carried out most of the fatigue testing.

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Measurement of Case Depth After Carburization

By J. Taylor, M.Sc., Ph.D.

SYNOPSIS

The difficulty of the precise definition and measurement of case depth is discussed. From the viewpoint of the carburization process, case-depth measurements ought to be related to the carbon-penetration curve. By the use of standard curves, carbon-penetration curves may be determined from two carbon analyses instead of the usual six or seven. Because of the variation of the diffusivity coefficient with carbon concentration, empirically derived standard curves are more reliable than those calculated from the mean value of the diffusivity coefficient. The importance is stressed of distinguishing between curves produced by straight carburization and those in which carburization is followed by a soaking period. 952

DIFFICULTIES OF MEASUREMENT

THE definition and measurement of the case after carburization is difficult and there is no general agreement on the best solution of the problem.[1–6] Since the transition from case to core is gradual the boundary cannot be defined exactly. Furthermore, the depth of hardened zone depends on factors other than the carbon content, so that it is difficult to correlate measurements based on hardness with those based on carbon penetration.

Carbon-Penetration Curve

For the study and control of the carburization process the complete carbon-penetration curve is the most satisfactory basis of comparison. To obtain six or more carbon determinations across the thickness of the case is somewhat laborious and for thin cases it is virtually impossible to obtain the required number of samples.

Microsection

Alternatively, microsection measurement is employed, but this too can be very unsatisfactory. In the course of an investigation into gas carburization[7] the depth of case was measured to the first perceptible increase in pearlite concentration. This is not a precise definition as it involves a personal factor, but by cross checking, agreement between different observers can be reached. Measurements by different laboratories, even on mild-steel specimens, were, however, hopelessly at variance. Even measurements on mild-steel specimens by the same observer showed considerable variation due to different degrees of annealing. The effect is illustrated by the results given in Table I. Measurements *A* were on carburized mild-steel specimens cooled down from 900° to 300° C. in 3 hr., and *B* were on the same specimens reheated to 915° C. and cooled down from 850° to 300° C. in 7 hr. There is a quite decided inward shift of the first 'perceptible' increase in pearlite concentration (the case/core boundary), a tendency for the measured hypereutectoid depth to increase, and for the eutectoid and the combined eutectoid and hypereutectoid depths to decrease. These results show that consistent microsection case-depth measurements, to this definition, depend on thorough annealing of the specimens. Thorough annealing of straight steel specimens is difficult and for most alloy steels is virtually impossible.

Table I
MEASUREMENTS OF CASE DEPTH

Specimen	Depth, mm.				
	Hyper-eutectoid (P.C)	Eutectoid (P)	Hypo-eutectoid (P.Fe)	P.C+P	Total
1 A	0·6	0·5	1·0	1·1	2·1
B	0·7	0·3	1·3	1·0	2·3
2 A	0·6	0·6	1·0	1·2	2·2
B	0·7	0·4	1·3	1·1	2·4
3 A	1·1	0·6	1·1	1·7	2·8
B	1·1	0·5	1·9	1·6	3·5

If, instead of the first 'perceptible' increase in pearlite concentration, the first 'pronounced' increase is taken as the case/core boundary, reannealing has little effect; the values are 1·64 and 1·65; 1·80 and 1·80; 2·39 and 2·45. But the 'first pronounced increase' is even vaguer than the 'first perceptible increase' and consequently is still more dependent on the observer. Unless, therefore, there is some method of standardization, agreement between different laboratories cannot be expected.

Use of Hardness Plots

To eliminate the personal factor the use of hardness plots, which can be carried out with reasonable speed, was considered. This method is undoubtedly the most

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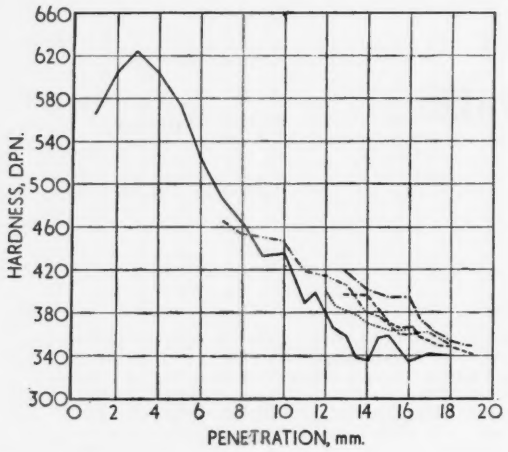

Fig. 1—Examples of hardness/penetration curves

satisfactory from the engineer user's viewpoint, the problem is to correlate the hardness plot with carbon penetration. In an attempt to eliminate the effect of cooling rates, the first tests were made on well annealed specimens. The specimens used were small billets with very deep cases for which carbon-penetration curves had already been determined. It was found that well annealed specimens were not suitable, the diamond indent often being smaller than the individual pearlite and ferrite areas. The samples were therefore heat-treated. Normally, cooling proceeds from the outside of the case inwards during quenching and the cooling rate progressively diminishes. To minimize this effect specimens with a polished cross-section were heated in an inert atmosphere to 900–910° C. and water-quenched. Cooling at the edges must still be more rapid but the difference must be much less than in the normal method. After repolishing, hardness plots were made across the case. The results were still unsatisfactory and the specimens were tempered at 400° or 500° C.; the effect of this difference in tempering temperature was negligible. This treatment gave the best hardness/penetration curves and they were determined on ten specimens. Hardness plots were made in quadruplicate, one for each side of the billet.

The type of curve obtained is shown in Fig. 1. As with carbon-penetration curves, the approach to the core value is asymptotic, and fixing the case/core boundary is difficult. Values for case depths determined in this way, together with values from carbon-penetration curves and microsection measurements on well annealed specimens, are given in Table II, which shows that the correlation between plots and carbon penetration is no better than between the latter and microsection measurements.

Case Depth Measurement Based on Carbon-Penetration Curves

Another aspect of the problem is the more precise definition of case-depth values derived from carbon-penetration curves, and how far any single value can express the results of such a curve. Measurement to the first perceptible increase above the original value, when the approach to that value is asymptotic, is unsatisfactory. Carbon-penetration curves also vary in shape. Take for example the curves shown in Fig. 2, taken from a paper on the diffusion of carbon during carburization.[8] Curves *f* and *g* show the carbon distribution for a straightforward carburization, in which the surface carbon concentration has been maintained constant. Curves *b* and *e* represent the carbon distribution for a diffusion-soak type of carburization, *i.e.*, one in which during the active-carburization period the surface-carbon concentration was constant at 1·45% and was afterwards reduced by soaking in an inert atmosphere. For the pair of curves *b* and *f*, the case depths, measured to where the curves approximate to the core value, are about the same. At 0·3% above the initial carbon the case depths are in the ratio $b/f = 1{\cdot}2$ and at 0·6% in the ratio $b/f = 1{\cdot}6$. The type of case represented by curve *b* would give both a greater zone of maximum hardness and a greater total hardened zone. In such instances single case-depth measurements can be most misleading.

OTHER METHODS

Gurry's Method

Two methods of approach to this problem *via* the weight of carbon absorbed per unit surface area have been proposed by Gurry[9] and Harris.[10] There is a relationship between the surface-carbon potential C_0, *i.e.*, the increase of the carbon concentration at the surface over that of the core, the diffusivity coefficient D, and the area enclosed by the carbon-concentration curve, *i.e.*, the weight of carbon absorbed per unit area. Gurry derived complete carbon-concentration curves from the latter value using known values of the diffusivity coefficient and assuming that the surface carbon concentration was that of saturated austenite. A mean value Dm of the diffusivity coefficient was used as it was claimed that the effect of the variation of D with carbon concentration was small. This method is restricted to the special instances when the surface layer is saturated with carbon.

Harris's Method

Harris's approach was rather similar except that he used the carbon-penetration curve to derive a precisely defined case depth which he called the

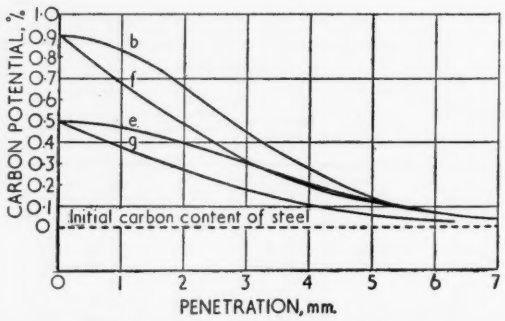

Fig. 2—Carbon-penetration curves

'apparent' case depth. He took a theoretical diffusion curve (calculated by using the mean diffusivity coefficient Dm) of the straight-carburization type represented by curves f and g in Fig. 2. If a straight line is drawn from C_0 to a point on the core-carbon ordinate so that the triangle enclosed is equal in area to that enclosed by the carbon-penetration curve, this straight line approximates quite closely to that curve over the major part of its length. Moreover, because D is in fact not constant but increases with carbon content, the agreement with the experimentally determined curves is still closer. Harris proposed therefore that the base P of this equivalent triangle be taken as the case depth. This 'apparent' case depth is derived from the weight of carbon absorbed per unit area as follows. If the ordinate units are carbon, %, and the abscissa penetration is in centimetres, the area of the equivalent triangle is

$$\frac{C_0 \times P}{2} \text{ cm.\%.}$$

Under unit surface of 1 sq. cm., the weight of carbon in grammes is given by

$$\frac{C_0 \times P \times \rho}{2 \times 100}$$

where ρ is the density of the steel. Hence if the weight of carbon absorbed per unit surface is w,

$$P = \frac{w \times 100 \times 2}{C_0 \times \rho} \text{ cm.}$$

Difficulty of Determining Surface Carbon Potential (C_0)

The drawback to both these methods is the determination of the value of C_0. As already stated, Gurry merely assumed carbon saturation at the surface and took the value for saturated austenite. Harris determined the surface-carbon concentration by milling off samples and analysing for carbon. This is also unsatisfactory, since the carbon gradient at the surface should be very steep and the slightest amount of surface decarburization or after-diffusion can cause a considerable drop in value without appreciably altering the remainder of the curve. The shape of the experimental curves given by Harris suggests that this has happened with most of his results. It was to be expected from the experimental conditions that the surface-carbon concentrations would be those of saturated austenite, but they are all low compared with the values given by Gurry.[11] If the surface-carbon concentration has decreased owing to a slight amount of surface decarburization, etc., it is, of course, the C_0 value before and not after this took place, which should be used in both the Gurry and Harris methods. Again, neither Gurry nor Harris took account of the different types of penetration curve.

Table II

MEASUREMENTS OF CASE DEPTH

Specimen	Depth, mm., from			Percentage Difference	
	Carbon-Penetration Curve (1)	Micro-section (2)	Hardness Plot (3)	(3) − (1)	(2) − (1)
*ES*2	8·7	7·6	7·1	−18	−13
*ES*3	14·8	15·0	14·8	Nil	+ 1
*ES*9*b*	12·8	11·7	13·1	+ 2	− 9
*ES*10*b*	12·0	13·0	13·8	+15	+ 8
*ES*11*b*	12·5	13·0	15·1	+21	+ 4
*ES*4	6·5	6·2	7·0	+ 8	− 5
*ES*8	13·0	11·8	13·3	+ 2	− 9
*ES*2	8·9	7·3	10·9	+22	−18
*ES*3	12·5	14·1	13·9	+11	+13
*ES*9	10·4	10·1	11·1	+ 7	− 3

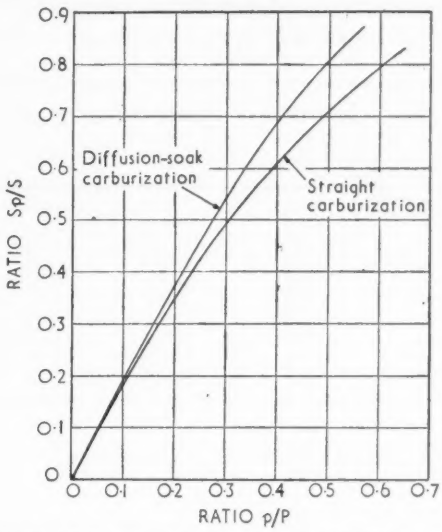

Fig. 3—Mean empirical curves for Sp/S vs. p/P

METHOD OF MEASUREMENT PROPOSED

A method whereby this difficulty of the direct determination of C_0 may be surmounted may be derived as follows. For penetration curves of the same type, there is a relationship between the ratio of the carbon absorbed Sp over a fraction p of the case to the total carbon S on the one hand, and the ratio of p to a standard measure of case depth P on the other. Harris's proposed 'apparent' case depth was taken as the definition of P. Data for eight carburizations at constant carbon potential[7] were taken and the relationship of p/P to Sp/S was determined. The mean empirical curve for these results is given in Fig. 3. Over the interval $Sp/S = 0{\cdot}25$–$0{\cdot}75$ or $p/P = 0{\cdot}15$–$0{\cdot}43$ all the values lay very close to this mean curve but there was some scatter over the upper and lower portions. Since the ratio $Sp/S = Wp/W$, where W is the weight of carbon absorbed per sq. cm. of surface, P can be estimated from Fig. 3 from determinations of W and Wp. The true surface carbon potential C_0 is then given by the expression used by Harris. From the values of C_0 and P the carbon diffusion curve can be estimated.

Straight Carburizations

The diffusion equation applicable to straightforward

Table III

VALUES OF x/P AND C/C_0 FOR STRAIGHT CARBURIZATIONS

$\frac{C}{C_0}$, % (1)	$\frac{x}{P}$ (theoretical), % (2)	$\frac{x}{P}$ (empirical), % (3)	$\frac{(3)-(2)}{(2)}$, % (4)
90	8·0	8·7	+ 9
80	15·9	17·0	+ 7
70	24·2	26·0	+ 7
60	32·8	35·0	+ 7
50	42·2	44·5	+ 5
40	52·7	54·8	+ 4
30	65·0	65·2	Nil
20	80·1	77·7	− 3
10	103·0	95·2	− 8
5	123·0	108·7	−12

carburizations in which the surface carbon concentration has remained constant is

$$\frac{C_0 - C}{C_0} = \frac{2}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{(Dt)}}} e^{-y^2} \cdot dy \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where C_0 = surface carbon potential
C = carbon potential at a distance x from the surface
D = diffusivity coefficient
t = carburizing time
$e^{-y^2} \cdot dy$ = Gauss error function.

The area S enclosed by a diffusion curve of this type is given by

$$S = 2C_0 \sqrt{\frac{Dt}{\pi}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Since

$$C_0 = \frac{2S}{P},$$

$$2\sqrt{(Dt)} = \frac{P}{2}\sqrt{\pi}.$$

Substituting in equation (1)

$$1 - \frac{C}{C_0} = \frac{2}{\sqrt{\pi}} \int_0^{\frac{2}{\sqrt{\pi}} \cdot \frac{x}{P}} e^{-y^2} \cdot dy.$$

From mathematical tables of the Gauss probability integral corresponding values of x/P and C/C_0 can be calculated. These are given in columns (1) and (2) of Table III, and the corresponding graph is plotted in Fig. 4*a*. When C_0 and P have been determined, corresponding values of x and C can be read off the curve in Fig. 4*a*. The carbon-penetration curve so determined is based on the assumption that D is independent of carbon concentration. Alternatively a reference curve can be constructed from experimental data which therefore allows for the variation of D with C.

Average values of the ratios of x/P to C/C_0 have been determined for about 30 carburizations, data for which are given in the papers of Bramley *et al.*,[12] Harris,[10] and Laidler and Taylor.[7] The empirical values of x/P are shown in column (3) of Table III, and the corresponding curve in Fig. 4*a*. The difference between these and the calculated values are shown in column (4). They vary from + 9% when $C/C_0 = 90\%$ to − 12% when $C/C_0 = 5\%$ and are an indication of the systematic error due to assuming D to be independent of carbon concentration.

Values of x have been calculated for the individual results by the method outlined and using the empirically determined standard curve. The comparison with the experimental values is shown in Table IV. In general the agreement is good, being poorest at the high carbon concentrations. This was to be expected because of the steep gradient of this portion of the curve and the effects of surface decarburization.

The data in Table IV are divided into the three groups, Bramley *et al.*,[12] Harris,[10] and Laidler and Taylor.[7] These show slight systematic errors, probably due to differences in carburization method. In the first group the surface-carbon concentration steadily increased during the whole carburization period, in the second it was constant for most of the time but evidently decreased slightly towards the end, and in the third group constant surface-carbon concentrations were maintained throughout. Except at high values of C/C_0 in the second group these systematic deviations are small and do not affect seriously the application of the method. Most types of straight carburization are therefore covered, the only exception being that in which the surface-carbon concentration decreases considerably towards the end of the time, either owing to exhaustion of the compound in pack carburization or to excessive soot formation in gas carburization.

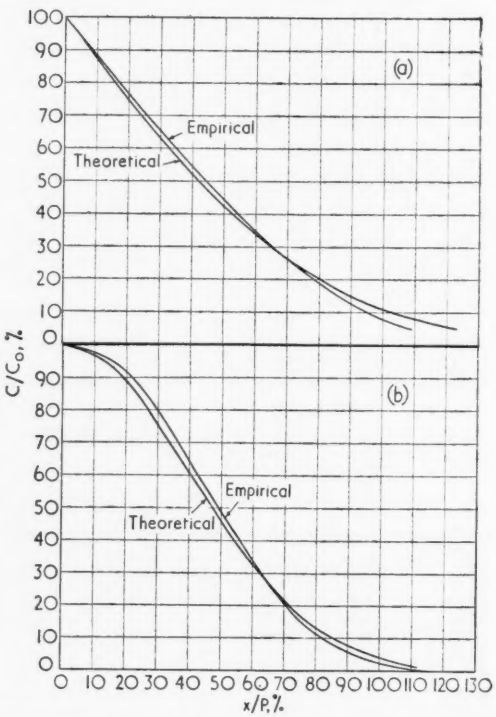

Fig .4—C/C_0 *vs.* x/P for (*a*) straight carburizations, (*b*) diffusion-soak carburizations

Diffusion-Soak Carburizations

It is clear that these calculations cannot apply to diffusion-soak carburizations, *i.e.*, those carburizations in which the active carburization period is followed by a soaking period in an inert atmosphere in order to reduce the surface-carbon concentration. These can, however, be treated in a similar way to the straight carburizations. In this case the carbon penetration curve is represented by the equation[8]:

$$C = \frac{H}{2\sqrt{(\pi Dt)}} \cdot e^{-\frac{x^2}{4Dt}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where H is a constant representing twice the amount of carbon diffusing under unit area of surface.

As in the case of straight carburizations the relationship between Sp/S and p/P must be determined empirically; Fig. 3 shows this curve, from which P and hence C_0 may be determined, and if the diffusivity coefficient is assumed constant a relationship between C/C_0 and x/P can be obtained from equation (3).

When $x = 0$

$$C_0 = \frac{H}{2\sqrt{(\pi Dt)}}.$$

But

$$H = 2S = C_0 \times P,$$

$$\therefore \quad 2\sqrt{(\pi Dt)} = P$$

and

$$4\,Dt = \frac{P^2}{\pi}.$$

Substituting in equation (3)

$$C = C_0 \cdot e^{-\frac{x^2\pi}{P^2}}$$

or

$$\log \frac{C}{C_0} = -\frac{\pi x^2}{P^2} \cdot \log e.$$

Values of x/P for given values of C/C_0 have been calculated from this expression and are shown in column (2) of Table V. The corresponding graph is given in Fig. 4*b*. As before, the assumption that D is constant introduces a systematic error in the estimated case-depth values and so the relationship of C/C_0 to x/P was also determined empirically (*see* column (3) of Table V and Fig. 4*b*). The percentage differences between the calculated and empirical values are given in column (4) of Table V.

Table V

VALUES OF x/P AND C/C_0 FOR DIFFUSION-SOAK CARBURIZATIONS

$\frac{C}{C_0}$, % (1)	$\frac{x}{P}$ (theoretical), % (2)	$\frac{x}{P}$ (empirical), % (3)	$\frac{(3)-(2)}{(2)}$, % (4)
90	18·3	21·8	+19
80	26·6	29·5	+11
70	33·7	36·0	+ 7
60	40·4	42·5	+ 5
50	47·0	49·1	+ 4
40	54·0	56·0	+ 4
30	62·0	63·0	+ 1·5
20	71·5	70·5	− 1·5
10	85·6	82·3	− 3
5	97·6	92·5	− 5

The data available for comparing calculated and observed penetrations are not so numerous as in straight carburization. Data from 12 carburizations have been examined and the percentage errors in the calculated values are shown in Table VI. The carburizations are arranged in two groups; three carburizations by Bramley and Lord[12] and four from Laidler and Taylor[7] make up the first group, and five from some experimental works carburizations the second. Extreme accuracy was not desired in the latter and the penetration curves are only approximate: this is reflected in the relatively poorer agreement. Even so, agreement between observed and calculated values is good for C/C_0 values less than 60%. The overall agreement is much better in the first group than in the second but even so when $C/C_0 > 80\%$ the errors become large. In diffusion-soak carburizations the carbon gradient near the surface is very gradual, so the agreement between the calculated and observed values of C_0 is good even for the second group of carburizations, as is shown by the following:

Group 1

C_0 (calc.)	0·93	0·88	0·69	0·59	0·67	0·58	0·58
C_0 (obs.)	0·91	0·86	0·68	0·60	0·64	0·56	0·54

Table IV

ERRORS IN CALCULATED VALUES OF CASE DEPTH AT DIFFERENT CARBON POTENTIALS

Reference	Kind of Result	Deviation, %, at Case-Depth Values Corresponding to Percentage C/C_0 Values of				
		5	20	40	60	80
Bramley *et al.*[12] (10 results)	**Maximum**	+10	+10	+ 9	−10	+24
	Average	5	5	4	5	7
	Systematic	+ 2·5	+ 3·5	+ 2·5	− 1·0	Nil
Harris[10] (average of 24 results)	**Systematic**	0	+ 3	− 2	0	+20
Laidler and Taylor[7] (9 results)	**Maximum**	+ 5	+10	+12	+ 7	−14
	Average	2·5	4	4	5	5
	Systematic	− 0·5	+ 2·0	+ 0·5	+ 0·5	− 3·0

Table VI

ERRORS IN CALCULATED VALUES OF CASE DEPTH AT DIFFERENT CARBON POTENTIALS FOR DIFFUSION-SOAK CARBURIZATIONS

Reference	Kind of Result	Deviation, %, at Case-Depth Values Corresponding to Percentage C/C_0 Values of				
		5	20	40	60	80
Bramley and Lord[12] and Laidler and Taylor[7]	Maximum	5	5	10	8	13
	Average	2	2	4	4	6
Experimental works carburizations	Maximum	11	8	13	22	...
	Average	5	5	7	11	...

Group 2

C_0 (calc.)	0·33	0·28	0·31	0·45	0·37
C_0 (obs.)	0·28	0·27	0·29	0·44	0·36

For the majority of carburizations the method described offers a relatively quick and easy means of obtaining a complete carbon-penetration curve and hence case depths referred to a particular carbon concentration. The type of carburization, whether straight or diffusion-soak, must, however, be known, and the method is not strictly applicable to the hybrid penetration curves, although in many cases of this type no serious error would be involved in applying the method. Carburizations with hybrid penetration curves not suitable for analysis by the above method are (i) pack carburizations, in which the compound has been exhausted before the end of the run, and (ii) gas carburizations, in which the steel becomes covered with a dense carbon skin or undergoes considerable decarburization.

Two carbon analyses only are required to determine the apparent case depth (P) and hence the penetration curve. If the total carbon absorbed per unit area (S) is determined by weighing, only one carbon analysis is necessary. Usually it will be preferable to take three samples across the case, *e.g.*, 0–20% of P, 20–35% of P, and from 35% to the depth where no further increase in carbon can be detected. These will give two values of Sp/S and hence two values of P, and by reference to the two curves in Fig. 3, a check on the type of curve, whether straight or diffusion-soak, will be obtained.

Possibly the Sp/S ratio might be determined by a method other than carbon analysis, *e.g.*, electrical and magnetic methods of measuring case depths have been proposed[13] but have not yet proved satisfactory. A drawback to such measurements is that the change in electrical or magnetic properties is a function of the total increased carbon content and not of the depth of penetration of carbon; this could be surmounted if the measurements were used to estimate an Sp/S ratio and hence the carbon distribution curve. For this it would be necessary to obtain a value for S on the test piece and then machine off a portion of the case and so obtain a value for Sp/S. Provided that the total carbon content can be estimated accurately, case depths to a definite increase in carbon concentration could be determined by such a method.

Conclusion

The method is suggested as a possible solution of the problem of measuring and assessing the carburized case. It is not so quick and easy as fracture and microsection measurements, but on the other hand it is probably easier and quicker than taper grinding, followed by hardness measurements across the case. No doubt for routine control, fracture and microsection measurements are more useful, particularly if calibrated from time to time by reference to some more exact method, such as the one proposed. Without such a standard, however, it is impossible to get agreement between different laboratories on fracture and microsection measurements. Moreover, with steels of different alloy and carbon contents, carburized under different conditions, no single case-depth measurement is an adequate guide and some method of determining the carbon-penetration curve or at least case depths measured to a definite carbon content is essential.

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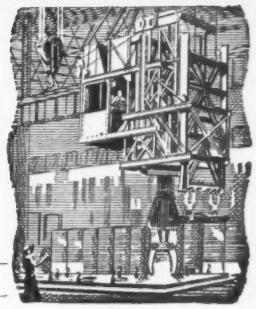

CLEVELAND INSTITUTION OF ENGINEERS

The Operation of Soaking Pits

By J. Dodd

SYNOPSIS

It is suggested that more fuel is used to prepare steel ingots for rolling than is necessary, having regard to the amount of heat contained in an ingot when teemed. The author suggests that economies in the use of fuel can be made by a greater use of heat-conservation pits, by more closely relating soaker capacity to actual need, by giving more attention to organization and utilization, and by good maintenance. 953

In the last few years as much has been written about soaking pits as about any other aspect of steelmaking. In a note recently produced by the British Iron and Steel Research Association dealing with information published on the subject between 1941 and 1952, the author gave 29 references. Thirteen of the references were concerned exclusively with design, five dealt mainly with experience in operation, and the remainder were concerned with associated problems, such as track time, planning, etc. The soaking pit seems to be an important item of steelworks plant, but it is a matter for concern that so much of the published information and discussion is confined to design and new types of installation. It may be thought that the best type of soaking pit is one-way-fired, with or without a precombustion chamber, or that certain recuperative systems have weighty advantages over others; nevertheless, the soaking pits actually in use are often 30 or 40 years old, and still deal adequately with ingot supply.

Owing to the high cost of modern installations, there is an understandable reluctance to replace these old furnaces so long as they can be kept in operation; at the same time, it is reasonable to ask whether there is any need for the complicated structures now being designed for heating ingots, from which enough heat to prepare them for rolling has probably already disappeared. Old furnaces can be made to work with a high degree of efficiency by giving close attention to such factors as heat conservation, organization and planning, utilization, track times, and the high availability that comes from first-class maintenance. At Appleby, the battery of soakers consists of three which are 27 years old, one which is 14 years old, and a small ingot preheater, which heats cold ingots up to 900° C. on the surface. This battery supplies a slabbing mill with 12,000–13,000 tons of ingots a week, of which 80% are charged hot, 15% come from the preheater, and 5% are dead cold; average heat consumption is 9 therms/ton. It has been stated (with the implied suggestion that it should be matched in the U.K.) that average U.S. practice is 10–12 therms/ton, with high proportions of hot-charged steel.

The most important influence on the efficiency of soaking-pit practice is, in the author's opinion, the one which generally receives the least attention, namely, the conservation of the steelmaking heat. Most plants have to work to a plan of some kind, maintenance is obviously necessary to ensure continuous running, and track time can be important only at those plants where layout and organization of ingot delivery can be improved. The conservation and use of the heat contained in ingots after teeming should command the attention of all those who operate soaking pits and, in addition, of all those who build them.

HEAT CONSERVATION

In 1882, Gjers began his paper on the invention of the soaking pit* with the following:

"*When Sir Henry Bessemer, in* 1856, *made public his great invention, and announced to the world that he was able to produce malleable steel from cast iron without the expenditure of any fuel except that which already existed in the fluid metal . . . , his statement was received with doubt and surprise. If he at that time had been able to add that it was also possible to roll such steel into a finished bar with no further expenditure of fuel, then undoubtedly the surprise would have been still greater.*"

He proceeded to explain that this had now come to pass, and described his arrangements for allowing the great heat in the liquid centre of an ingot to permeate the whole mass, producing an ingot of uniform temperature for rolling without the use of any external means of heating.

A revised version of a paper presented at a meeting of the Cleveland Institution of Engineers, held at the Cleveland Scientific and Technical Institution, Middlesbrough, on 1st February, 1954.

Mr. Dodd is Plate Mills Manager of the Appleby-Frodingham Steel Company.

* *J. Iron Steel Inst.*, 1882, No. II, pp. 565–573.

There is, as Gjers discovered, more heat in an ingot when teemed than is subsequently required to bring it up to rolling temperature and yet, according to the Anglo-American Productivity Report on Iron and Steel and other authorities, in average practice in this country 17 therms/ton are expended on reheating. This fact is quite properly a subject of concern. About 17 million tons of ingot were heated last year, and therefore, if the figure of 17 therms per ton is accurate, 289 million therms were used to reheat ingots which had been (or could have been) at a good uniform temperature for rolling at some time between teeming and charging. This colossal figure represents over a million tons of coal, and saving half that amount would be worthwhile.

Investigations into the reduction of fuel consumptions generally lead to the need being expressed for more instrumentation and automatic control; this might have some small effect, but it does not get to the core of the problem. The original soaking pit, which gave its name to the modern ingot-reheating furnace, made use of the contained heat in the newly stripped ingot to condition it for rolling. If for some reason the ingots became cold, they were reheated in some form of furnace fired with coal or producer gas. No time was lost between teeming and stripping and, as this interval has an important bearing on mould life, it is possible that moulds lasted a good deal longer in those days.

The development of the soaking pit seems to indicate that steel-producers and furnace builders turned to the design of reheating units rather than to better facilities for heat conservation, so that a soaking pit to-day is generally such only in name. It is recognized that there must be means of heating cold ingots—ingots made at a weekend, imported ingots, and those made at a time when a mill stoppage prevents soaking-pit space being emptied to take them—but in an integrated works great fuel economies could be achieved if research and experiment were properly applied to the subject of heat conservation.

Gjers pits (*see* Fig. 1) have been used at Appleby-Frodingham with varying success ever since the plate mills began to operate 27 years ago. They were originally lined with firebrick, each cell being large enough to hold three 10-ton ingots. Mainly because of badly shaped ingot bottoms, which required the ingots to lean against the walls, damage to the walls was considerable, and the near-impossibility of maintaining them nearly led to the use of these pits being discontinued some years ago. Refractory linings were replaced by cast-iron slabs, backed by insulation brick, and the lids were given a monolithic lining. The lid lifting gear, previously operated by remote control from the soaking-pit platform, was given a more practical form. These modifications made for tremendous savings in maintenance and, although it is not claimed that the heat-conserving qualities of cast iron are equal to those of firebrick, 10-ton ingots have actually been rolled direct from these pits. This feat cannot often be repeated, and output would be low if it was adopted as a practice, but the fact that it can be done at all should encourage research into means of conserving and using steelmaking heat. The fact that it is possible to roll large ingots, which have had no heat input, from such improvised pits, casts doubts on whether the industry is justified in using over a million tons of coal a year on reheating.

ORGANIZATION AND UTILIZATION

No matter what means of conserving heat or reheating are available, one of the most important things in operating soaking pits is planning. So long as heating costs are of the order of 10*s*. per ton, it is necessary to plan the occupation of soaking pits with care, so as to reduce heating times and mill delays to a minimum.

Organization depends upon many factors, the most important of which is steel supply. The advent of the large tilting furnace and the growth of its use have increased the problem, and good liaison between the soaking pits and the melting shop is the first and probably the most important step towards solving it. Those operating soaking pits must know in good time what steel is being made, when, and in what quantity; they must also know the size of ingot, and any aspect of melting-shop organization likely to affect delivery after teeming. The melting shop must know of mill stoppages which arrest the flow of ingots from the soaking pits; they must know when an extra cast might be useful, when an anticipated stoppage owing to a shortage of steel might be avoided by a light charge after tapping, and when small-size ingots, which are ready for rolling sooner, will be preferred to large ones. Each department should be aware of what the other is doing and intends to do, and something of the difficulties that prevent one department from doing something the other would like to be done.

Soaking pits form a reservoir which is fed, under the best conditions, with a supply of steel which is irregular by comparison with the rate at which it is emptied. At Appleby-Frodingham, the slabbing mill rolls about 750 tons per shift, and the steel supply is about 85% of the production of seven 300-ton furnaces. Five of those furnaces have on occasions tapped within a shift, and, on the other hand, periods of 8 hr. without any furnaces tapping are not rare. Since the local industry is dependent on home ores, with high sulphur content, the difficulties of steel refining have to be appreciated, and so a regular supply cannot be expected. It is the planner's responsibility to ensure that the mill is fed regularly and continuously, without excessive soaking times. This is acknowledged to be almost impossible, but the nearer it is approached, as measured in terms of avoidance of heat delays and low fuel consumption, the greater will be the output and the lower the cost.

Utilization of soaking pits is obviously a major factor affecting efficiency, and this is found to vary with soaker capacity. In a section mill, it was noted recently that four soaking pits were used to the extent of 46%; during a week when one of these was off for repairs, the other three were used to the extent of 61%, and the mill rolled the same tonnage. The accepted practical possible figure is about 65%, so that in this plant it can be said that three soakers provided too great a capacity to be efficient, although the production could not have been achieved with

Fig. 1—Gjers pits, showing lid lifting gear

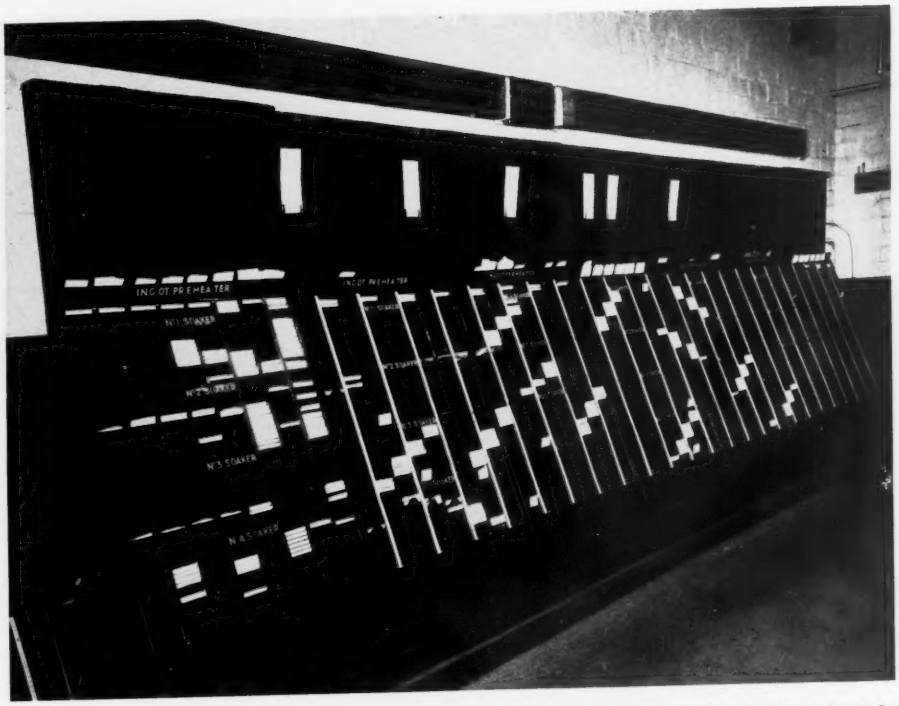

Fig. 2—The plan board used to ensure maximum occupation of the soaking pits at Appleby

[*To face p.* 298

less than three of that size. Mill managers have always complained of having too small a soaker capacity, and that is perhaps why, in new steelworks, an excessive capacity is, in the author's opinion, installed. The mistake of trying to eliminate heat delays by the addition of more soaking pits is too easily made, and can lead to excessive soaking times, with increased scaling losses and reduced yield.

Efficient utilization depends upon a number of considerations. It is often difficult to know, despite the best possible liaison, whether to fill an empty soaking pit with cold ingots or to leave it empty for hot steel. The best forecast can prove to be optimistic, and so it is advisable to charge cold ingots instead of waiting for steel which by some mischance is made later than was expected. Space in other soakers will very likely be vacant before the hot steel arrives. When a slabbing mill is serving more than one mill, ingots for different mills are often taken simultaneously from different soakers. Space made available in one soaker should be filled by transferring ingots from another, so as to be able to recharge and maintain maximum occupation. Plants where wet slagging is the practice can be expected to have a lower utilization figure than those where cinder is dug out. Those plants using coke-breeze bottoms possibly have a still lower figure.

Maximum utilization cannot be achieved without some visual system of planning. No man can remember sufficient details of such factors as when steel furnaces are going to tap, what type and quantity of steel is to be made, which soakers should be charged cold, when to leave empty for slagging, etc. At Appleby there is a fairly elaborate system which works well in practice. It is based on tapping forecasts; the visual signals are posted on a plan board (*see* Fig. 2) representing ingot positions in the soakers. The steel furnaces usually take about 18 hr. from tap to tap, and, as soaker planning is done for a 12-hr. period, 6 hr. after tapping permits a reasonably accurate forecast of the next tap by the time it comes within the soaker planner's range. A card is posted on the plan board, under the forecast time, and small blank cards, representing the ingots to be made, are posted on the board in a position corresponding to that to be occupied in a soaking pit by the ingots they represent, under the time they can be expected to be ready for rolling. The positions of these cards are altered as the tapping forecast alters but, before the ingots arrive for charging, where they will be charged and when they will be ready for rolling is already known. Soaking time is based on a schedule of heating times worked out from observations made on the heating of ingots many years ago, and covers all conditions from cold-charged ingots to those charged in the minimum time after tapping.

The plan board is divided and subdivided to represent the occupation of the soakers both at the present time and for at least 12 hr. ahead; the plan is to have six ingots ready for rolling in each ½ hr. The card posted on the plan board indicating the tapping forecast is divided by perforations, each subdivision representing a cast; on these cards are entered details of the casts intended to be made. When a furnace taps, this master card is split into cast cards, which are posted on the board under the actual tapping time. Cards representing each ingot are prepared, showing cast number, ingot size, etc., and these cards replace the blank cards posted on the board at the time of the original forecast. A glance at the plan board at any time shows the anticipated tapping times and whether these are to be bunched or spaced; it shows the number of ingots ready or to be ready for rolling into slabs for each of two plate mills, and for sale; and it shows the times during the next 12 hr. when there will be no ingots ready for rolling, and when a delay for heat cannot be avoided. This last condition is particularly useful, as it enables the maintenance engineers to postpone work which otherwise would delay the mill if done at the time when the need for it is discovered; the task can be planned and prepared for, with a saving of time in its execution. Delays for heat do occur and, despite the best planning and most efficient organization, will occur until steel supply more nearly approaches perfect regularity. It is difficult to give an accepted satisfactory figure for stoppages caused by the lack of ingots ready to roll, as conditions in rolling mills vary so widely and as few mills record their stoppages with sufficient precision to make comparisons possible; however, during a week when over 13,000 tons of ingots were rolled, delays from this cause amounted to less than 7% of the total working week.

MAINTENANCE

When operating soakers which have a smaller capacity than is necessary or desired, it is very necessary to ensure maximum availability, and good maintenance is of prime importance. In plants which have an annual stop period of two weeks, or two periods of one week each, it should never be necessary to be without the complete soaker installation, unless a continuous working week is being operated. It is possible to do everything except major repairs at a weekend, with no more than a few hours loss of production time, and such items as relinings, wall topping, repairs to bonnet arches, etc., should be such as to maintain 98% availability. At Appleby the time taken to wreck and replace a working lining deprives the mill of the use of the soaker for only a few hours. Replacement of checkers should not be necessary in less than 3 years from building, and such items can be dealt with during the stop period.

The amount of maintenance necessary on soakers depends to a large extent on the precautions taken to avoid the need for repair. Bad driving of clumsily designed cranes can undo in minutes repairs that have taken hours to perform. On the rolling-cover type of pit, water leaking from hydraulic cylinders will perish brickwork in bonnet arches, and a new gland packing which will last for more than a few hours is necessary. Hydraulic operation of rolling covers is preferable to electrical operation; it has been established at Appleby that maintenance on soaker covers moved electrically is 50% more than on those operated hydraulically, owing to the greater disturbance of bricks caused by the quicker and more jerky action of electrical equipment. Fins on the bottoms of ingots cast on to bad bottom plates will tear out a section of front lining, and ingots with badly shaped bottoms

will topple over, causing damage to brickwork. The biggest single cause of damage to walls is the shape of the ingot bottom, where this is other than flat. When ingots have to lean against the wall there is considerable damage, due both to abrasion and to the effect of oxidation, and the saving in maintenance resulting from the use of flat-bottomed ingots which do not have to touch the wall must be substantial.

DISPOSAL OF CINDER

To maintain maximum soaker availability it is imperative that soakers should not have to be taken off for the removal of cinder, and it is difficult to understand why this should be such a problem as it appears to be in so many plants. It is not easy to understand why slag, which melts at a temperature below that normally operating in soakers, should be allowed to accumulate until it forms a depth of 2–3 ft., and then have to be dug out. There are convincing arguments for dry slagging, but a practice which denies the use of a soaking pit for almost a week cannot be justified when slag removal by flow, if not easy, is possible. Extensive wear to linings and lids is said to result from the practice of carrying maximum heat beyond the time required for heating ingots, and this is probably true. But there is no point in saving maintenance, which can be done in non-productive time, if a soaker, as a result, has later to be lost to production for about a week. Moreover, a soaker designed to work at a depth of 7 ft. cannot be expected to work efficiently at less; before the end of a campaign a single ingot is often to be found lying across a pit, occupying the space of two.

The organization of slagging by flow is difficult in plants where soaker capacity is small, and where maximum utilization is necessary. In these circumstances the charging of any substantial quantity of cold ingots does not help. A soaker bottom chilled off by a charge of cold ingots can take a day to recover, and only then if successive charges of hot ingots are put in. Thus, steel supply has an important bearing on the problem of slag disposal.

Despite its low melting point, the removal of liquid slag is admittedly not easy, but a big factor in its success is the will to do it. It is a task which requires constant attention, so as to take advantage of every opportunity as it occurs. It is possible to run slag from a soaking pit stocked with ingots, and, provided that the operating staff are in favour of wet slagging, there is no reason why a soaker bottom should not be maintained at its maximum depth without ever having to be dug out. There can be no half-measures; the temptation to avoid an opportunity for slagging is, at times, too great to be resisted if a policy of partial digging out is practised. Dry slagging makes the burden of supervision lighter, but the advantages to be gained from maintaining a soaker constantly at its designed working level, and, in addition, maintaining maximum soaker availability, far outweigh the advantages claimed by those who advocate and pursue a policy of dry slagging.

It may be asked at this stage, " Why slag at all ? Why make slag ? " In these days of controlled combustion and furnace atmospheres the accumulation and disposal of cinder would not be expected to be such a problem. It is significant that even the most modern pit incorporates elaborate and expensive arrangements for slag disposal. The arrangement whereby slag mixes with coke breeze and is pushed out of the bottom adds enormously to the cost of installation in foundation work alone, in addition to reducing availability during operation. The fact that the very latest designs provide means of disposal suggests that the day when no slag will be made is still distant.

Scale formation is encouraged by time, temperature, and furnace atmosphere. Ingots might be rolled at lower temperatures than is usual, and would thus require less heating time, but present requirements of steel call for progressively greater throughput, which cannot be obtained by lowering the rolling temperature. Moreover, it is sometimes advantageous to encourage the scaling of some ingots, so as to remove the ingot skin and avoid surface defects in the slab or bloom. A reducing atmosphere results in a scale which is difficult to remove, and which can cause surface pitting in a finished plate. Slag formation can be controlled and inhibited to some extent, but the amount that cannot be prevented must be removed.

CONCLUSION

This paper has dealt exclusively with problems encountered in operating soakers, particularly old ones, and a discussion of the various types of soaking pit should be the subject of a future paper. Future developments in soaking pits should be directed towards a less interrupted continuation of steel-making. Transport of hot ingots after stripping is a gross misuse of men and machines. The man-hours and capital expended on the manufacture and operation of complicated systems of ingot transfer could well be used in more profitable ways. The semi-continuous bogie-type reheating furnace is a highly successful unit, and it does not seem to be an impossible development that the bogie should become the casting car, that a train of ingots should be stripped on the same line as the furnace entry, and that ingots, molten within, should be given a true soaking during passage through such a furnace. This would be a return to the original conception of a soaking pit, but with the benefits of many years of experience of insulation, control of furnace atmospheres, etc. The result would be a uniformly heated ingot, with all its advantages—great economy of fuel and manpower, savings in capital, no slag, and little maintenance.

The input of heat into an article which was originally far hotter than it is required to be is a waste of the country's most vital commodity, coal, and it represents a challenge which cannot be ignored. More than 70 years ago, Gjers kept his mill at Darlington going on ingots, in his own words, " rolled with their own initial heat," and in a 12-hr. shift he rolled 300 ingots, however small; in the discussion following the presentation of his paper, it was stated that a mill in West Cumberland rolled 2000 tons of ingots in a week, a big tonnage in those days, using no fuel for reheating. This leads to the conclusion that soaking-pit practice must have taken a wrong turning somewhere: the time has surely now come for an investigation of the possibilities of reverting to the use of contained heat.

IRON AND STEELWORKS ENGINEERING

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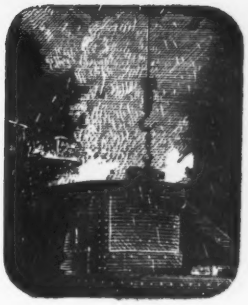

Melting-Shop Reconstruction at the Normanby Park Steel Works

By J. A. Peacock, M.I.C.E.

JOHN LYSAGHT'S SCUNTHORPE WORKS LTD.

SYNOPSIS

The paper deals with the reconstruction of the melting shop to increase average ingot production from 7000 to 10,500 tons per week and briefly describes the plant replaced and the new plant installed. The project is taken in three stages to show how arrangements were made to maintain the highest possible ingot output per week throughout the reconstruction period.

The method adopted for dismantling and widening the casting bay from 54ft. 6in. to 70ft. span is dealt with, and also the problems experienced in the civil engineering field, and the changeover from a narrow-gauge railroad system handling 60-ton heats to a normal broad-gauge system to handle 120-ton heats cast into a single ladle, with the necessary larger-capacity ladle cranes and casting equipment.

Reference is also made to the new stripping bay and the mould shop, which gives facilities for cooling, cleaning, and changing ingot moulds. 1005

As part of the general reconstruction scheme at John Lysaght's Scunthorpe Works Ltd., and to increase average ingot production from 7000 to 10,500 tons per week, it was essential to modify the melting shop and ancillary equipment to achieve this output.

The scheme envisaged involved building one new 120-ton furnace, and rebuilding one 90-ton and six 60-ton furnaces to 120 tons capacity. To handle this increased tonnage, it was necessary to widen the casting bay from 54 ft. 6 in. to 70 ft. span, to replace the three 75-ton ladle cranes by three of 175 tons capacity, to install three new mechanical casting stands in place of the old fixed stands, to build a complete new stripping bay with two new stripping cranes, to dismantle, re-site, and extend by 150 ft. the existing mould preparation shop, and to effect a complete changeover from 3-ft. narrow-gauge to standard broad-gauge tracks. The layout of the existing plant is shown in Fig. 2. A summary of the work carried out is given in Table I, and some constructional data in the Appendix.

To keep outputs as high as possible during the modification period, it was decided to approach the job in three stages, so that the maximum number of furnaces could be kept in production at any time, and to cause as little dislocation to traffic as possible (*see* Fig. 3). By doing this, the average weekly outputs achieved during the various stages were :

Stage 1	6894 tons
Stage 2	5944 tons
Stage 3	7259 tons.

STAGE 1

This stage involved the south end of the plant adjacent to furnace *H*, which was the only site available for the new furnace *J*. Details are given in Fig. 6*a*. The existing building was modified over furnace *H*, and an extension of 116 ft. was made to house the new furnace *J*.

Furnace *H* was increased in capacity to 120 tons, and a new static teeming stand and one new 175-ton ladle crane were installed in this section to handle the output from these two furnaces. Meanwhile, work had been in progress in laying the necessary broad-gauge tracks from the new static stand in the casting bay into the adjacent partly completed stripping bay, where ingots are stripped before being pushed into the soaking pit bay, ready for charging to the pits. At this stage it was necessary to handle both narrow- and broad-gauge traffic for transfer of ingots, and a combined three-line track was installed between the stripping and soaking pit bays for this purpose.

Method of Dismantling and Re-erection of Building

As the existing railroad layout at the south end of the melting shop was used for transferring blast-furnace slag to the tarmac plant and for the disposal of slag, rubbish, etc., from this end of the existing shop, it was found impossible to erect a scotch derrick

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crane for the erection of the building steelwork without seriously disrupting the running of the plant.

The method finally adopted for this erection programme was to use stationary guy derricks with guys attached to loaded winches, and steam cranes. All the wire guys had to be placed so that they did not interfere with normal traffic and had to be checked for clearance each time a derrick was moved to a new position. Arrangements were also made for traffic to approach the site at all times with caution. All heavy columns and girders were brought in as required on 40-ton wagons. By this means, and with very strict liaison between all departments, erection proceeded without a hitch and delays to the plant were kept to a minimum.

As the sequence of erection of the building steelwork was from south to north, it was possible, after about half had been erected, for erection of one of the 175-ton cranes to proceed. Here again a guy derrick had to be used in conjunction with lifting trusses and steam cranes. The sequence of crane erection was as follows :

The main girders of the crane, being in three sections, were first brought into the end of the new shop and set up on packings by steam crane; after being lined up and checked they were then riveted.

Table I

SUMMARY OF WORK CARRIED OUT

Section of Work Involved	Detail	Stage 1 (5.4.51–21.6.51)	Stage 2 (18.9.51–7.6.52)	Stage 3 (7.6.52–9.10.52)	Total
Excavation	Column foundations	4934 cu. yd.	495 cu. yd.	335 cu. yd.	14,184 cu. yd.
	Furnace *J* foundations	4281 „	...	...	
	Furnace platform foundations	45 „	104 „	91 „	
	Ancillary plant foundations	471 „	580 „	1082 „	
	Trench	952 „	447 „	367 „	
Drainage	Length and size of drains: 6 in.	223 yd.	356 yd.	476 yd.	1055 yd.
	9 in.	192 „	62 „	33 „	287 „
	12 in.	347 „	78 „	...	425 „
Concrete	Column foundations	3861 cu. yd.	373 cu. yd.	279 cu. yd.	8081 cu. yd.
	Furnace *J* foundations	2021 „	...	...	
	Furnace platform foundations	39 „	92 „	71 „	
	Ancillary plant foundations	345 „	344 „	656 „	
Steelwork and corrugated sheets	Tonnage dismantled	554 tons	1360 tons	1299 tons	3213 tons
	Tonnage erected	4563 „	1408 „	1353 „	7324 „
	3 175-ton ladle cranes	215 „	430 „	...	645 „
	2 6-ton ingot strippers	259 „	...	...	259 „
Rail tracks laid	Permanent broad-gauge track	466 yd.	697 yd.	1800 yd.	7355 yd. (4·17 miles)
	Temporary „ „ „	1055 „	1827 „	583 „	
	„ two-gauge track (soakers)	83 „	...	...	
	„ narrow-gauge track	737 „	107 „	...	
	Permanent broad-gauge crossings	6	12	36	94
	Temporary „ „ „	13	12	...	
	„ narrow-gauge „	13	2	...	
	Permanent broad-gauge diamond crossings	2	1	...	10
	Temporary broad-gauge diamond crossings	...	3	...	
	Temporary broad- and narrow-gauge diamond crossings	4	...	...	
Rail tracks removed	Existing broad-gauge track	417 yd.	630 yd.	200 yd.	7228 yd. (4·11 miles)
	Temporary „ „ „	650 „	1517 „	1381 „	
	Existing narrow- „ „	330 „	2103 „	...	
	Existing broad-gauge crossings	4	8	3	55
	Temporary „ „ „	5	8	3	
	Existing narrow- „ „	3	21	...	
	Temporary broad-gauge diamond crossings	...	...	3	8
	Existing narrow-gauge diamond crossings	1	4	...	

Meanwhile, the end carriages were brought in and erected; they were lashed to the building as a temporary measure until the main girders were erected. By arrangement with the departments concerned for a clear period, the crane girders were then rolled into position near the derrick and winched up and fixed to the end carriages. The other components were then brought in and erected as circumstances permitted, each trade following in turn to complete the necessary stages.

During this time work had been proceeding on the building of furnace *J* and the platform steelwork, the installation of the ladle bricking pits and the ladle dryer, and making the necessary modifications to railroads, etc. Everything was dovetailed so that all was ready, by the time the building was completed, for furnaces *H* and *J* to be put into production, all necessary foundations having been put in previously.

Summary—Stage 1

(1) Started erecting building columns 18th January, 1950: columns *A*4, *A*5, *A*6, *D*2, *D*3, *D*4, *D*5, *D*6, and *D*7.

(2) Started erecting roof and gantry girders 13th February, 1950.

(3) Started dismantling and re-erection of existing mould shop 10th June, 1950.

(4) Erection of 175-ton crane begun 21st July, 1950; ready for testing on 30th September, 1950.

(5) Stopped tipping slag on old tarmac site 28th August, 1950.

All the above work was completed without interference with the existing plant.

(6) Furnace *H* taken off 5th April, 1951, and started stripping existing building. Furnace *H* gassed 16th June, and tapped 22nd June, 1951.

(7) Furnace *J* gassed 26th June, and tapped 2nd July, 1951.

Figure 1 gives a view in the casting bay looking south, and shows the new furnace *J* tapping, with the existing bay, which was dismantled in stage 3, in the background.

Preparation for Stage 2

Meanwhile, work had been in progress on clearing the site of engineering workshops, fume extraction plants, gas washers, railroads, etc., along the east side of the old casting bay, installing new column bases for *A* line and erecting building columns, and erecting the stripping bay and mould shop. To keep the existing narrow-gauge tracks for ingot traffic to and from the plant in operation, it was found necessary, before these column bases could be put in, to bridge over the excavations and in some cases to slew the tracks to clear the line of the new columns (*see* Fig. 5). All this preliminary work had to be completed so that all columns and girders on *A* line could be completely erected before starting dismantling for stage 2, with the exception of gantry and roof girder *A*19–*A*20, which was left out for dismantling purposes. As it was impossible to put in the valley column bases (*D* line) while the plant was working a seven-day week, it was decided to tackle this section during the works annual shut-down, and to put in as many foundations as possible, together with intersecting connections for drains

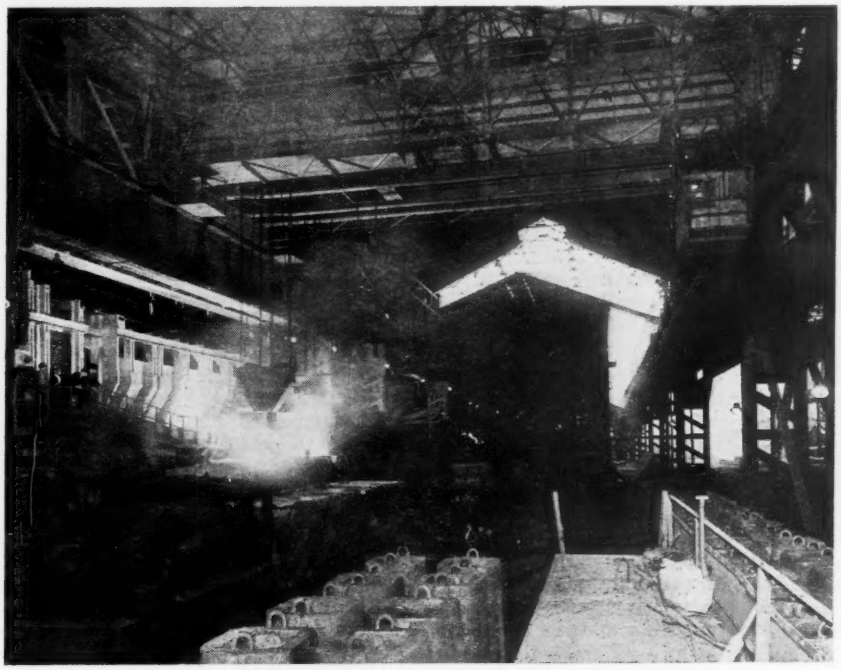


Fig. 1—View of casting bay, showing furnace *J* tapping, with existing casting bay in background

which had to cross the charging bay to the main drain, during this period.

This in itself was a major operation, since these foundations had to go under the furnace foundations in some cases as far as 5 ft., all foundations being designed for a maximum loading of 3 tons/sq. ft. Figure 5 shows the column bases in relation to furnace and drainage plan. Column bases *D*8, *D*9, *D*10, *D*11, *D*13, *D*14, *D*15, and *D*16 were completed during this period, leaving bases *D*12, *D*17, *D*18, and *D*19 to be put in during stages 2 and 3, owing to site conditions.

Before a start could be made on stage 2 it was necessary to make provision for getting hot metal into the centre of the existing shop without interfering with the dismantling and re-erection programme. To do this a temporary railroad was put in from near blast-furnace *A*, joining up with the slag road opposite the boiler plant and then crossing over the boiler breeze road and narrow-gauge roads into the centre of the shop. This meant installing temporary diamond crossings so as not to dislocate other traffic (*see* Fig. 6*b*). Hot metal for furnaces *H* and *J* was taken from the existing shop by transfer bogie.

STAGE 2

Mixer 2 and furnace *A* were taken off on 18th September, 1951, and a start was made on dismantling the existing building. The method agreed for this section was that all dismantling and re-erection would be done by steam derrick cranes on bogies, with the exception of heavy columns and girders, which were to be erected with stationary guy derricks, which could be moved rapidly by using the derrick cranes for placing them into position. Owing to congestion at the north end of the plant it was found that insufficient room was available for erecting the first derrick crane in the line required to start dismantling until the first 100 ft. had been dismantled; to get over this the first derrick crane was erected on 12th September, 1951, outside the casting bay on the east side for the initial dismantling. This enabled the gable end and the roof of the first 100 ft. of the casting bay to be dismantled. The second derrick crane was then erected on 20th October, 1951, in the dismantled section and proceeded with dismantling. As soon as it had cleared sufficient space, the first derrick crane was taken down and re-erected in the casting bay, using the second crane for this purpose, ready for re-erection of the roof steelwork on 22nd October, 1951.

As the valley line between the casting and charging bays was being rebuilt it was necessary to dismantle the roof of the charging bay. This was accomplished by using a guy derrick on the charging floor and stacking the roof trusses and purlins on the charging floor for re-erection by the same method later.

Since the existing valley columns were on approximately the same site as the new columns *D*18 and *D*19, it was necessary to dismantle these columns before the old foundations could be replaced by new ones. As soon as these columns were removed, the old foundations were cut out and the new bases were installed; day and night work proceeded and by 13th October, 1951, the first column (*D*19) was in position and erection began.

Before mixer 2 and furnace *A* were taken off, furnace *B* had been taken off for a complete rebuild. It was intended that furnaces *C* and *D* should be kept in operation until this furnace had been rebuilt, but unfortunately furnace *D* had to be withdrawn from service, and so had to be brought into the rebuilding programme with furnace *B*. This, in a way, was a blessing in disguise, as it enabled dismantling to proceed over furnace *B* while rebuilding of furnace *D* proceeded, and so less slag traffic was passing out of the north end of the shop, impeding construction work. It also allowed the extension of furnace *C* slag road to be coupled up with the temporary hot-metal road into the centre of the shop, and the valley columns and gantry girders, weighing approx. 25 and 60 tons, respectively, to be brought into position as required for erection; the first roof and gantry girders were erected on 24th–25th October, 1951.

As erection of steelwork proceeded, the roof sheeting followed and a start was made on sheeting the charging bay on 3rd November, 1951, and the casting bay on 11th November, 1951.

Owing to the very tight programme set, it was essential for the erection of the two remaining 175-ton cranes to follow immediately so that this in turn would not hold up the railroad programme. A start was made on assembling the crane girders outside the casting bay at the north end opposite the boiler plant on packings ready for lining up and riveting on 27th October, 1951. These in turn were then lowered on to bogies running on two parallel roads at 40-ft. centres and transferred into the shop to be erected by guy derrick.

The end carriages for the first crane were erected on 11th November, 1951, the first main girder on 16th November, the auxiliary girders on 19th November, and the second main girder on 22nd November. These were followed by the other components, and the crane was completed by 22nd December, 1951, ready for test. Meanwhile, erection of the second crane had been proceeding, and this was completed and ready for test by 15th January, 1952. The railroad programme then began at the north end of the shop and followed the erection sequence.

Furnace *C* was taken off on 12th November, 1951, and dismantling proceeded to completion for stage 2. The first existing 75-ton crane was dismantled on 13th December, 1951, leaving two cranes to work the old shop.

To facilitate rebuilding on mixer 2 and furnaces *A* and *B*, a charger was put back into the newly erected section of the shop on 6th December, 1951, using temporary gantry girders to bridge the gap between the old and new sections during transfer. This enabled work to proceed to completion on these furnaces, and by 24th January, 1952, mixer 2 was gassed. Both 175-ton ladle cranes were tested with a test load of 220 tons on 30th January, 1952, and the first charge was put into mixer 2 on 7th February, 1952. Furnace *A* was also gassed on 7th February, and on 10th February mixer 1 was taken off to enable stage 2 of the building programme to be completed by 29th February, 1952.

As soon as mixer 1 was taken off, hot metal from mixer 2 had to be transferred to feed furnaces *E*, *T*,

Fig. 2—Melting shop: layout of existing plant

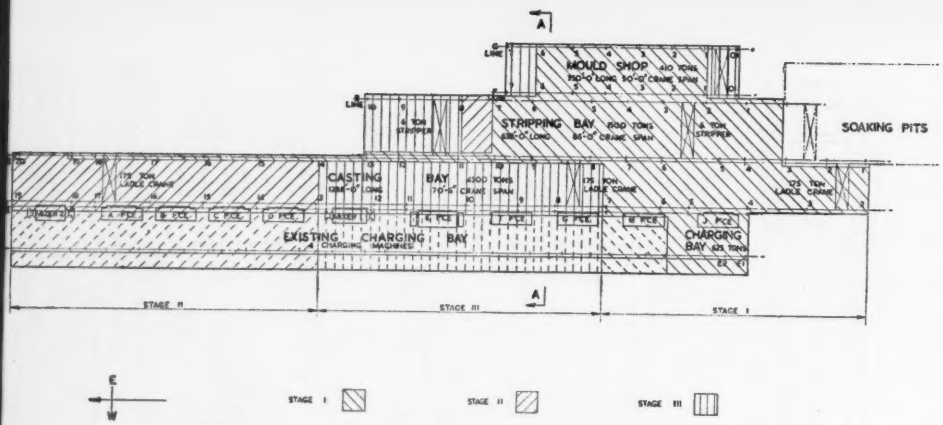


Fig. 3—Stages in extension and reconstruction

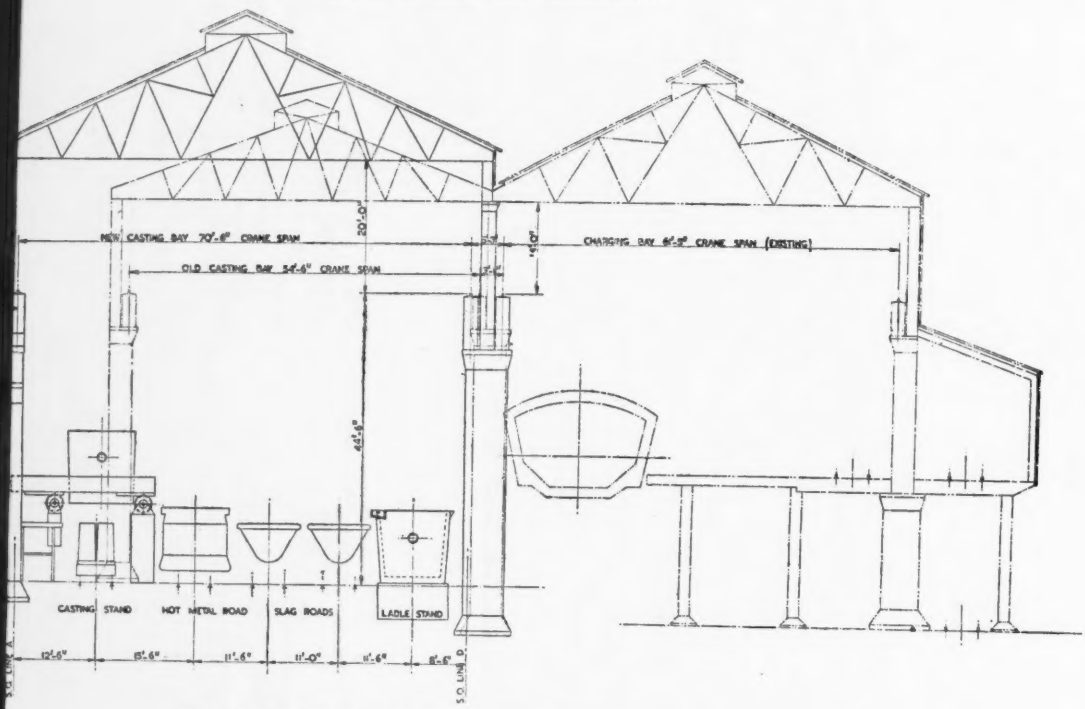
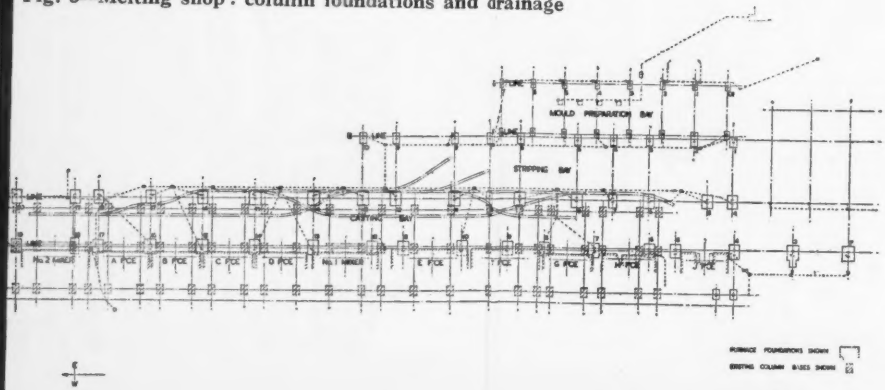


Fig. 4—Section through casting and charging bays

Fig. 5—Melting shop: column foundations and drainage



[Peacock
[To face p 304

G, *H*, and *J*. As the previous method of transfer into the centre of the shop would hold up dismantling and re-erection, it was decided to feed it to the south end of the shop and to reverse the transfer method adopted during stage 1 for furnaces *H* and *J*.

Furnace *A* was charged on 13th February, 1952, and tapped at 3.10 p.m. on 14th February, furnace *B* being charged and tapped on 1st March, 1952. As the first mechanical teeming stand was not ready, a temporary static teeming platform had been erected to handle the output from furnaces *A* and *B*.

A second charger was put through into the new section on 19th February, 1952, to handle the reconstruction work on furnaces *C* and *D*; furnace *D* was charged on 28th March, 1952, and tapped on 29th March. Mechanical teeming stand *A* was put into operation on 10th April, 1952, and furnace *C* was charged on 6th June and tapped on 7th June, 1952.

During this period all railroad work in this section had been installed and stage 2 was completed and back in production by 7th June, 1952 (*see* Fig. 6*b*).

STAGE 3

Shortly after mixer 2 and furnaces *A* and *B* had been put back into production, and while stage 2 was being completed, it was essential for dismantling to begin on stage 3 for continuity of the programme. Furnace *E* was taken off on 9th March, 1952, and furnaces *T* and *G* on 18th March. This enabled dismantling of the remainder of the old plant to proceed without hindrance, and, as the narrow-gauge railroads were now redundant, these were all pulled out on 19th March, 1952, releasing the site for the completion of the broad-gauge system of railroads. The two existing 75-ton cranes were dismantled, together with the building steelwork, and, since mixer 1 weighbridge was now redundant, this was pulled out to make room for the new weighbridge foundation; it also enabled column foundation *D*12 to be completed, thereby releasing the site for erection to proceed.

Dismantling of the old building was completed by 30th April, 1952, erection of the charging-bay roof by 13th May, and the casting bay by 6th June, when the overhead cranes started travelling the full length of the shop (*see* Fig. 4).

Meanwhile, furnace *E* had been put back into production on 30th May, 1952, and work was proceeding on casting stands *B* and *C*, ladle stands, drainage completion, the installation of a 160-ton weighbridge, the completion of railroads for the casting bay, stripping bay, and mould shop, and the foundation for the ingot weighbridge.

So as not to interfere with the ingot traffic, it was agreed to complete the roof of the stripping bay and to install the ingot weighbridge during the works annual stop period in July, and also to complete the changeover of the railroad system.

Furnace *T* was put back into production on 31st July, 1952, and furnace *G* on 3rd October, 1952. This completed stage 3 (*see* Fig. 6*c*).

During the construction of the various stages, as much of the permanent railroad was laid as possible, in addition to the temporary construction and hot-metal tracks. In this connection, the ingot traffic before the reconstruction was handled by three narrow-gauge steam locomotives dealing with casts from 60-ton ladles. All ingot traffic is now handled by one 204-h.p. Diesel standard-gauge locomotive.

CONCLUSION

The success of a job of this magnitude was only achieved by careful planning and the determined efforts and fullest co-operation of all concerned to overcome the many day-to-day problems which arose.

APPENDIX

Constructional Data

Column Foundations

Base Dimensions—Casting Bay

A line varied from 20 ft. × 15 ft. to 22 ft. × 18 ft.
D line varied from 20 ft. × 16 ft. to 22 ft. × 18 ft.
Foundation bolts : 4 × 1¾ in. dia.
Excavation : 4652 cu. yd. Concrete : 3473 cu. yd.

Base Dimensions—Stripping Bay and Mould Shop

B line varied from 16 ft. × 10 ft. to 17 ft. × 11 ft.
Foundation bolts : 4 × 1¾ in. dia.
F and *G* lines: 12 ft. × 7 ft. Foundation bolts : 6 × 1½ in. dia.
Excavation : 1111 cu. yd. Concrete : 1040 cu. yd.
All bases were designed for a ground pressure of 3 tons per sq. ft.

Steelwork

A line columns	18–23 tons each (approx.)	
B line columns	13 tons each (approx.)	
D line columns	25 tons each (approx.)	
A line roof girders, max. span	12 tons each	
D line roof girders, max. span	13 tons each	
B line roof girders, max. span	11½ tons each	
A line gantry girders, max. span	62 tons	Casting bay
D line gantry girders, max. span	62 tons	Casting bay
D line gantry girders, max. span	31 tons	Charging bay
B line gantry girders, max. span	45 tons	Charging bay
Charging bay roof trusses	2½–3 tons	
Casting bay roof trusses	2¾ tons	
Stripping bay roof trusses	3½–4 tons	
Rack bracing, *A* line, max. span	5 tons (approx.)	
Rack bracing, *D* line, max. span.	1½ tons (approx.)	

(Shorter spans in proportion)

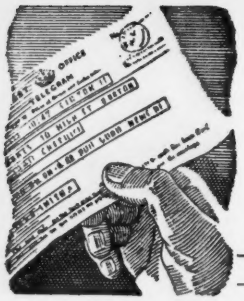
Total weight of steelwork and corrugated sheets :

Erected	7324 tons
Dismantled	3213 tons

Wheel loads (175-ton cranes) :
72 and 70 tons loaded
42 and 40 tons unloaded

Three 175-ton ladle cranes, each 215¼ tons : Total 645¾ tons

Two 6-ton ingot strippers, each 129½ tons : Total 259 tons



NEWS

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Autumn General Meeting 1954

The **Autumn General Meeting** of The Iron and Steel Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday and Thursday, 17th and 18th November, 1954.** The detailed programme of the Meeting was given in the October issue of the *Journal*, p. 183.

B.I.S.R.A. Open Days

An error has been made in the **Reply Form I for the 1954 Autumn Meeting,** which has been circulated to Members of the Institute. The dates given on the lower half of the page for the Open Days at the B.I.S.R.A. Laboratories at Battersea should read **Thursday, 18th November,** and **Friday, 19th November,** instead of Wednesday, 17th, and Thursday, 18th November, as printed.

Symposium on Powder Metallurgy, 1954

A **Symposium on Powder Metallurgy,** organized by The Iron and Steel Institute in association with the Institute of Metals, will take place in the Hoare Memorial Hall, Church House, Westminster, London, S.W.1, on **Wednesday and Thursday, 1st and 2nd December, 1954.** The arrangements have been entrusted to the following Organizing Committee:

Dr. IVOR JENKINS (*Chairman*)	General Electric Co., Ltd.
Mr. L. J. BRICE	Ministry of Supply
Dr. W. D. JONES	Powder Metallurgy Ltd.
Mr. D. A. OLIVER, C.B.E.	B.S.A. Group Research Centre
Dr. L. B. PFEIL, O.B.E., F.R.S.	Mond Nickel Co., Ltd.
Dr. T. RAINE	Metropolitan-Vickers Electrical Co., Ltd.
Mr. E. ROBSON	Manganese Bronze and Brass Co., Ltd.
Mr. K. HEADLAM-MORLEY (*Secretary*)	The Iron and Steel Institute
MR. A. E. CHATTIN (*Assistant Secretary*)	The Iron and Steel Institute

The fifty papers contributed to the Symposium cover both ferrous and non-ferrous metallurgy, and have been divided into four groups; each group will be presented by a rapporteur. The Symposium is open to all interested in the subject, whether members of The Iron and Steel Institute or the Institute of Metals or not, and tickets of admission will not be required.

A small Exhibition of powder-metallurgy components will be held in Committee Room No. 6 at Church House during the days of the Symposium. It will be open from 9.30 A.M. on both days, and will close at 7.45 P.M. on 1st December, and 5.0 P.M. on 2nd December.

After the Meeting the papers and discussion will be published in a bound volume of Proceedings, price £3 5*s*. 0*d*. per volume, post free. Orders for bound volumes should be accompanied by a remittance. In the case of orders received before the Meeting, one set of preprints of the papers will be provided free in respect of each volume ordered; preprints will not be supplied without an order for a bound volume.

The detailed programme of the Symposium is as follows (a complete list of the papers in each group was given in the October issue of the *Journal*, pp. 183–184):

Wednesday, 1st December

Morning Session

9.30–9.45 A.M.—The Hon. R. G. Lyttelton, President of The Iron and Steel Institute, supported by Dr. S. F. Dorey, C.B.E., F.R.S., President of the Institute of Metals, will welcome the participants

9.45 A.M.–12.45 P.M.—Presentation and discussion of papers in Group I—"*Manufacture, Properties, and Testing of Powders.*" The Chairman will be Dr. Ivor Jenkins and the Rapporteur Dr. A. L. Northcott

12.45–2.15 P.M.—Buffet Lunch in Bishop Partridge Hall, Church House (tickets price 5*s*. 6*d*. each).

Afternoon Session

2.15–5.30 P.M.—Presentation and discussion of papers in Group II—"*Principles and Control of Compacting and Sintering.*" The Chairman will be Dr. W. D. Jones and the Rapporteur Dr. A. Blainey.

5.45–7.45 P.M.—Reception in the Restaurant, Church House. The Hon. R. G. Lyttelton and Dr. S. F. Dorey, Presidents of The Iron and Steel Institute and the Institute of Metals, will receive participants, who are welcome to bring friends (tickets price 12*s*. 6*d*. each).

Thursday, 2nd December

Morning Session

9.30 A.M.–12.45 P.M.—Presentation and discussion of papers in Group III—"*Manufacture and Properties of Structural Engineering Components.*" The Chairman will be Mr. E. Robson and the Rapporteur Dr. P. R. Marshall

12.45–2.0 P.M.—Buffet Lunch in Bishop Partridge Hall, Church House (tickets 5*s*. 6*d*. each).

Afternoon Session

2.0–5.0 P.M.—Presentation and discussion of papers in Group IV—"*Powder Metallurgy of High-Melting-Point Materials.*" The Chairman will be Mr. D. A. Oliver, and the Rapporteur Mr. B. E. Berry.

Fatigue Tests on Rolled Alloy Steels

The Institute has published the fiftieth of its Special Report Series, a report entitled "*Fatigue Tests on Rolled Alloy Steels Made in Electric and Open-Hearth Furnaces.*" It has been prepared for the Fatigue and Inclusions Committee of the British Iron and Steel Research Association.

The report presents the results of a very extensive

series of fatigue tests carried out on various steels with the object of relating metallographic examination to engineering performance, particularly in connection with non-metallic inclusions.

This report is an important contribution to the study of the factors influencing the fatigue strength of alloy steels and should stimulate further work in this field.

The report is to be discussed during the Autumn Meeting of the Institute this month.

Copies of Special Report No. 50 may be obtained from The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1, at 25*s*. per copy, post free (15*s*. to Members).

W. B. Wragge

It is regretted that there was an omission from the final printed version of the biography of Mr. W. B. Wragge, which appeared as a Frontispiece to the September, 1954, issue of the *Journal*. The words " of James Mills Limited " should be inserted at the end of the second sentence in the second paragraph.

NEWS OF MEMBERS

▶ Mr. K. T. BASSETT has been awarded the degree of B.Sc. in Metallurgy of the University of Durham, and has joined the Fairey Aviation Co., Ltd., Hayes, Middlesex.

▶ Dr. B. FLOYD BROWN has left the North Carolina State College to join the Naval Research Laboratory, Washington, D.C.

▶ Mr. W. F. GILBERTSON has been appointed Deputy General Manager and Works Superintendent of the Ebbw Vale Works of Richard Thomas and Baldwins Ltd.

▶ Dr. P. K. GLEDHILL has left the North East Coast Laboratories of B.I.S.R.A. to join Dorman, Long and Co., Ltd.

▶ Mr. R. S. GODWIN has left the U.K. and has taken up an appointment in the Metallurgy Department of Lucas-Rotax Ltd., Toronto, Canada.

▶ Mr. K. T. GOODCHILD has been awarded the degree of B.Sc. in Metallurgy and has been made an L.I.M.

▶ Dr. H. M. OTTE has left the Columbia University School of Mines, and has joined the Metallurgical Laboratory of the University of Illinois, U.S.A.

▶ Mr. D. J. PHILLIPS has been awarded a 1st Class Honours degree and the Sidney Gilchrist Thomas Medal in Metallurgy at the University College, Swansea. He has now taken up an appointment with Rolls Royce Ltd., Derby.

▶ Mr. G. A. PICKUP has left H.M. Forces and has joined the Park Gate Iron and Steel Co., Ltd.

▶ Mr. K. N. SRIVASTARA has left the U.K. for India and has taken up an appointment in the National Metallurgical Laboratory, Jamshedpur.

▶ Dr. C. SYKES, Managing Director of Thomas Firth and John Brown Ltd., has been appointed a member of the Advisory Council for Scientific and Industrial Research.

▶ Mr. J. C. WRIGHT has been awarded the degree of B.Sc. of London University.

▶ Dr. O. ZMESKAL has left the Illinois Institute of Technology to join the College of Engineering, University of Florida.

CONTRIBUTORS TO THE JOURNALS

S. H. Brooks, B.Eng., A.M.Inst.F.—Senior Assistant in the Fuel Engineering Section of the Research and Development Department, United Steel Companies, Ltd.

Mr. Brooks was educated at Ecclesfield Grammar School and at Sheffield University, where he graduated with Honours in Fuel Engineering in 1943. He then spent 2½ years as a Technical Assistant in the Directorate of Gas and Heat Supplies of the Ministry of Supply.

S. H. Brooks

F. A. Gray

During this time he was engaged in fuel economy surveys of factories, etc. His next post was as Assistant Fuel Engineer at the Corby works of Stewarts and Lloyds Ltd., where he remained until taking up his present appointment in 1948. Mr. Brooks has since been mainly concerned with research on reheating furnaces, sintering of iron ore, oil fuel firing, and fluid flow problems.

James Dodd—Plate Mills Manager with the Appleby-Frodingham Steel Co.

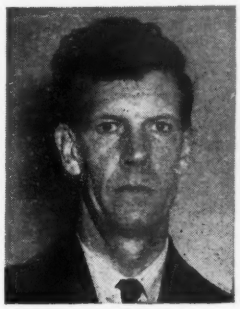
Mr. Dodd was born at Scunthorpe in 1913, and was educated locally. On leaving school he joined the United Steel Companies, Ltd., under their executive staff training scheme. He has since held various assistant management posts with the Appleby-Frodingham Steel Co., and took up his present appointment in 1951.

F. A. Gray, F.Inst.F., A.I.M.—Fuel Engineer in the Research and Development Department of the United Steel Companies Ltd.

Mr. Gray received his technical education at the University of Sheffield and was awarded the Associateship in Metallurgy in 1922. His early appointments were with Thos. Firth and Sons, Ltd., and John Brown and Co., Ltd., first at the Brown-Firth Research Laboratories, and later with the Fuel Department, on its formation in 1925. In 1930 he was appointed Fuel Engineer to Samuel Fox and Co., Ltd., and was responsible for the organization of the Fuel Department of the Company. He took up his present appointment in 1945.

Mr. Gray has been concerned for many years with the utilization of fuel in the iron and steel industry, and is the author of several papers on various aspects of the subject. He is a member of Council of the Institute of Fuel and was Chairman of the Yorkshire Section of the Institute for the session 1952–53. He is also a Member of Council of the British Coal Utilisation Research Association.

J. Savage, B.Sc., F.Inst.P.—Head of the Physics Department of the British Iron and Steel Research Association.



J. Dodd

J. Savage

Mr. Savage received his technical education at the University of Nottingham, and was awarded the degree of B.Sc. of London University with 1st Class Honours in Physics and Mathematics in 1936. He then joined the Ship Carbon Co. of Great Britain Ltd. as a research physicist, remaining with the Company until 1944 when he left to take charge of spectrographic work at the Royal Aircraft Establishment at Farnborough. He joined B.I.S.R.A. in 1947 as Head of the General Physics Section; in the following year he became Deputy Head of the Physics Department, and in 1953 he succeeded Professor M. W. Thring as Head of the Department. He has since been primarily responsible for the Association's research and commercial development of continuous casting. He was elected a Fellow of the Institute of Physics in 1952.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

London Group Open Days at Battersea

Some of each of the Association's main types of work, including direct applied research, background, and fundamental work, will be shown at the London Group Open Days at the Battersea Laboratories, 140 Battersea Park Road, London, S.W.11, on Thursday and Friday, 18th and 19th November, 1954. The main exhibits are those of the Physics and Chemistry Departments and the Plant Engineering Division. They also include Operational Research and some of the researches of the Ironmaking Division, carried out at the Imperial College of Science and Technology. The exhibition will show rather more of the laboratory type of research and less of the larger scale work and its direct application to steelworks plant and production processes than is typical of the Association's research programme as a whole. This is because London, with its access to libraries and the headquarters of learned societies, is suited to the more fundamental side of the Association's work, whereas the application of results is more easily carried out in its other laboratories. The work shown is, however, in most cases directly related to works problems.

The Physics Department will exhibit work on fuel technology, instruments, fluid flow, and general physics; the Chemistry Department will show work on the physical chemistry of iron and steelmaking processes, refractories, and the prevention of corrosion; and the Plant Engineering Division will cover electrical, mechanical, and civil engineering aspects of steelworks plant equipment.

Information about transport to the Laboratories is obtainable from the Information Officer, B.I.S.R.A., 11 Park Lane, London, W.1. Visitors who require lunch and tea are asked to inform the Association in advance.

Eighth Junior Steelmaking Conference

The Eighth Junior Steelmaking Conference was held at Ashorne Hill on 23rd–24th June, 1954, under the General Chairmanship of Mr. W. Geary. The first session, at which the Chairman was Mr. A. N. Whiting, was devoted to "*Sulphur in Steelmaking.*" It opened with a paper by Mr. N. H. Bacon, in which he showed the benefits of a low sulphur content in the finished steel and detailed the steps that could be taken in any steelworks to reduce to the minimum the sulphur burden in the furnace by the careful selection, grading, and pretreatment of materials. The second paper was presented by Dr. J. Pearson, who considered the physico-chemical aspects of sulphur in the steelmaking process. He showed that although there is a fairly good understanding of the equilibrium metal/slag and slag/gas sulphur distributions, it is not possible yet to apply this knowledge directly to a furnace in the form of explicit instructions for making low-sulphur steel. It was evident from the ensuing discussion that the members were fully aware of the increasing problems of sulphur in steelmaking and were alive to the methods by which this problem could be overcome.

The second session, at which the Chairman was Mr. W. C. Fletcher, was devoted to "*The Use of Various Fuels in the Open-Hearth Furnace.*" Mr. W. Jackson spoke on the use of various fuels in 300-ton tilting furnaces and gave details of production, fuel, and refractory consumption for one melting shop which, over seven years, had used three types of fuel. A second paper on this subject, given by Mr. W. B. Wright, considered the fuels used in connection with the heat transfer problem in an open-hearth furnace. Mr. Wright showed that the B.I.S.R.A. burner, which was designed for maximum jet momentum, was a both efficient and flexible apparatus and had given complete satisfaction over a long period of working.

The last paper presented in this session was by Mr. R. Mayorcas who spoke on the application to open-hearth furnaces of fundamental work on flame radiation and heat transfer. He showed that although many useful results had emanated from researches to date a complete understanding of heat transfer in an open-hearth furnace required further work on such aspects as the heating of scrap by convection and the degree of gas penetration into the scrap as a result of increased flame momentum. Experiments on these lines were being conducted both in the laboratory and in the steelworks.

INSTITUTE OF METALS

The Council has elected Mr. HUBERT SANDERSON TASKER a Fellow of the Institute of Metals, in recognition of his distinguished services to the Institute. The total number of Fellows of the Institute is limited to twelve.

General Meeting, London

A special General Meeting of the Institute of Metals will be held at 4 Grosvenor Gardens, London, S.W.1, on 25th–26th November, 1954. A session to be held on 25th November will comprise eight papers on "*The Constitution of Titanium Alloys,*" and two sessions on the following day will have as their main themes "*Preferred Orientation*" and "*Corrosion and Staining of Aluminium Alloys.*" Non-members of the Institute will be welcome at the meeting; tickets are not required.

NEWS OF SCIENCE AND INDUSTRY

B.S.C.R.A. Research Bursary

Applications are invited from suitably qualified graduates for a bursary provided by the British Steel Castings Research Association, tenable in the Department of Metallurgy of the University of Cambridge. The successful applicant will be required to undertake research, which could lead to the Ph.D. degree, into the causes and prevention of intergranular fracture in steel castings. The bursary is similar in amount to current D.S.I.R. maintenance allowances and is tenable for two years with renewal for a third year.

Applications, giving full particulars, should be addressed directly to Dr. T. P. Hoar, Department of Metallurgy, Pembroke Street, Cambridge.

Information Courses for Staff

The South Wales and Monmouthshire Area Training Committee of the British Iron and Steel Federation is holding courses, each of twelve lectures, dealing with the main processes, economics, and organization of the iron

and steel industry. The courses are intended primarily for commercial and administrative staff who wish to extend their knowledge of the industry; they are being held in Cardiff, Newport, Swansea, Llanelly, and Briton Ferry.

Meeting on Corrosion—Frankfurt

A meeting on corrosion has been arranged simultaneously with the Annual Meeting of Dechema, and will be held in Frankfurt-am-Main on 11th–13th November, 1954. A session on 11th November will comprise ten papers dealing with "*The Nature and Causes of Corrosion*," and ten further papers to be presented on 12th November will have as their main theme "*Processes for the Prevention of Corrosion*." A number of works visits in the neighbourhood of Frankfurt will be arranged on the third day of the meeting.

Midlands Electronics Exhibition

The Scientific Instrument Manufacturers' Association will hold an exhibition of electronic aids to production, design, and research, under the title "*Electronics at Work*," in the Chamber of Commerce Hall, Birmingham, on 23rd–25th November, 1954. The exhibition theme will be exemplified by a large number of working demonstrations showing the employment of electronics in a wide range of industrial applications, in public services, medicine, and education, and in varied spheres of research and development.

Admission will be by ticket obtainable free on request from the Association at 20 Queen Anne Street, London, W.1, or from the Birmingham Chamber of Commerce, the Birmingham Exchange and Engineering Centre, or the City of Birmingham Information Department.

New Blooming Mill at Lackenby

The new blooming mill for the Lackenby Works of Dorman, Long and Co., Ltd., will be the largest of its type operating in Britain. It will be a 52 in. × 112-in. reversing blooming and slabbing mill, designed to roll ingots weighing from 4·4 tons of 23-in. square section up to 20 tons with a shaped section of 52 in. × 41 in. Its primary purpose will be to produce blooms for subsequent conversion into broad flange beams ranging in size from 6 in. × 4 in. to 36 in. × 16½ in., but it will also roll rectangular or shaped blooms for joists, channels, angles, and sheet piling, in addition to slabs up to 50 in. wide. The mill, whose output will be of the order of 15,000 tons/week, will be driven by two 4000-h.p. R.M.S. motors, each with a maximum capacity of 12,000 h.p. It will be equipped with universal manipulators and tilting gear, all necessary main and auxiliary roller tables, ingot-tilting chair, and ingot weighing equipment. A 1350-ton hydraulic open-sided upcutting bloom and slab shear with pump and accumulator drive will also be supplied, together with approach and run-out tables and a nine-chain transfer bank, and will be capable of cutting slabs up to 10 in. × 50 in. or equivalent section up to a maximum thickness of 19½ in. The contract for the fabrication of the mill has been placed with Davy and United Engineering Co., Ltd.

Coke Oven Plant

A new coke oven plant, valued at about £2½ million, is to be built at Ravenscraig, near Motherwell, by Colvilles Ltd. as part of their £20-million Scottish steel development scheme. The installation will carbonize 1600 tons of coal per day, and will comprise 700 Woodall-Duckham Becker coke ovens, coal handling, storage, and blending plant; coke handling and screening plant; by-products equipment; benzole recovery and rectification plant; water recirculation and cooling equipment.

Gas Carburizing

For many years the case hardening of steel components by gas carburizing has been favourably accepted as an alternative to the traditional pack methods. Precise metallurgical control of the quality of the case is possible and carburization can take place at high temperatures. A widely used technique is to employ an atmosphere of prepared towns' gas, treated to remove decarburizing constituents. An alternative technique of employing directly a liquid mixture fed into the furnace has, in the past, resulted in a tendency for sooting unless the mixture is rigidly controlled. This difficulty is claimed to be overcome with the introduction of 'Carbodrip' by Wild-Barfield Electric Furnaces Ltd., of Watford. This liquid mixture has successfully undergone laboratory and full scale tests and has produced repetitive gas analyses and metallurgical results.

The equipment for flow control and drip feed to the furnaces, at a pressure of 5–10 lb./sq. in., is simple and relatively cheap and is especially suitable for conditions where towns' gas is not readily available. An important feature of 'Carbodrip' is that it has the same carburizing potential as prepared towns' gas so that performance is the same. Practical trials on a range of En steels have confirmed this and have shown that metallurgical control is simple and accurate. The equipment may be operated on standard furnaces and the process can also be used for carbonitriding.

Technical details of the process and results of pilot trials may be obtained from the Company at Elecfurn Works, Watford.

Quality of Carburizing Atmospheres

A new instrument for measuring the quality of a carburizing atmosphere has been developed by the General Electric Co., Ltd. It consists essentially of a compartment, with a transparent front, inside which is an iron wire that is carburized in the atmosphere under test and cooled rapidly so that it is transformed to martensite. In this condition the electrical resistance of the wire is a measure of its carbon content and hence of the carburizing potential of the atmosphere. Values of the electrical resistance of the quenched wire can be directly related to carburizing potential from a calibration curve. Operation of the gauge is straightforward, and one measurement takes about 15 min.

Birlec Limited

Following negotiations between Associated Electrical Industries Ltd., the Mond Nickel Co., Ltd., and Birlec Ltd., it has been announced that Birlec Ltd., formerly a wholly-owned subsidiary of the Mond Nickel Co., Ltd., has been sold to Associated Electrical Industries Ltd. Birlec will operate as an individual company within the A.E.I. Group.

CORRIGENDUM

Some Factors Affecting the Wear of Graphite Electrodes in the Electric-Arc Furnace

The Electric Process Sub-Committee have been informed of an error in this paper (*J. Iron Steel Inst.*, 1954, vol. 176, Feb., pp. 159–165). On p. 161, under the heading "Mechanism of Wear," the second paragraph begins "The combustion rates of all forms of carbon increase rapidly with temperatures up to 1100° C. Between 900° and 1100° C., for example, in a slow-moving air stream (3 cm./sec.), the combustion rate increases fivefold.[4]"

Examination of the reference given shows, however, that between these two temperatures the combustion rate increases by about only 40%. This difference is

likely to be misleading, particularly since the paper referred to also shows that between 1100° and 1400° C. there is little further increase in combustion rate.

DIARY

1st Nov.—INSTITUTE OF BRITISH FOUNDRYMEN (Sheffield and District Branch)—"*Castings versus Fabrications*," by H. Mottram—College of Technology, Pond Street, Sheffield, 7.15 P.M.

2nd Nov.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Some Theoretical Aspects of Practical Rod Rolling*," by E. W. Gregory—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 P.M.

3rd Nov.—NEWPORT AND DISTRICT METALLURGICAL SOCIETY (Joint meeting with The Iron and Steel Institute)—"*Some Notes on the New Plant at Shotton*," by J. F. R. Jones—Whitehead Institute, Cardiff Road, Newport, 7.0 P.M.

4th Nov.—INSTITUTE OF METALS (Birmingham Local Section)—"*Metallurgical Research in the Electrical Industries*," by I. Jenkins—James Watt Memorial Institute, Great Charles Street, Birmingham, 6.30 P.M.

4th Nov.—INSTITUTE OF METALS (London Local Section)—"*Trends in Metallurgy*," by A. G. Quarrell—Royal School of Mines, South Kensington, London, S.W.7, 7.0 P.M.

8th Nov.—INSTITUTION OF PRODUCTION ENGINEERS (Sheffield Section)—"*Boron Steels*," by R. Wilcock—Grand Hotel, Sheffield, 6.30 P.M.

9th Nov.—SHEFFIELD METALLURGICAL ASSOCIATION—Discussion on Open-Hearth Furnaces: Basic Roofs—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 P.M.

9th Nov.—INSTITUTE OF METALS (South Wales Local Section)—"*Some Aspects of Creep*," by J. P. Dennison—Metallurgy Department, University College, Singleton Park, Swansea, 6.45 P.M.

10th Nov.—MANCHESTER METALLURGICAL SOCIETY—"*X-Rays in Metallurgical Research*," by E. A. Calnan—Lecture Room, Central Library, Manchester, 6.30 P.M.

10th Nov.—NORTH WALES METALLURGICAL SOCIETY—"*Fracture of Metals*," by E. C. Rollason—County Primary School, Plymouth Street, Shotton, Chester, 7.15 P.M.

10th Nov.—SWANSEA AND DISTRICT METALLURGICAL SOCIETY (Joint meeting with The Iron and Steel Institute)—"*Some Factors Affecting Open-Hearth Steelplant Performance*," by J. S. Curphey—Central Library, Swansea, 7.0 P.M.

11th Nov.—STAFFORDSHIRE IRON AND STEEL INSTITUTE—Works visit to the Midland Rollmakers Ltd., Crewe, followed by "*Modern Techniques in Roll Making*," by K. H. Wright—Castle Hotel, Newcastle-under-Lyme, 7.0 P.M.

16th Nov.—SHEFFIELD METALLURGICAL ASSOCIATION (Joint meeting with the Sheffield Society of Engineers and Metallurgists and the Institute of Metals)—"*Specifications—Friends or Foes?*" by S. Barraclough—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 P.M.

17th Nov.—INSTITUTE OF FUEL (Yorkshire Section)—"*Flame Radiation Research*," by M. W. Thring—Royal Victoria Station Hotel, Sheffield, 2.30 P.M.

17th–18th Nov.—THE IRON AND STEEL INSTITUTE—Autumn General Meeting—4 Grosvenor Gardens, London, S.W.1.

18th Nov.—EBBW VALE METALLURGICAL SOCIETY—Presidential Address: "*Surface Defects Associated with Hot Strip Rolling*," by J. J. Beese—R.T.B. Lecture Hall, 7.15 P.M.

18th Nov.—LIVERPOOL METALLURGICAL SOCIETY—"*The Fracture of Metals*," by C. E. Phillips—Liverpool Engineering Society, The Temple, Dale Street, Liverpool, 7.0 P.M.

18th–19th Nov.—BRITISH IRON AND STEEL RESEARCH ASSOCIATION—Exhibition of the work of the London Group of Laboratories—140 Battersea Park Road, London, S.W.11.

19th Nov.—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—"*Direct-Reading Spectrographic Analysis of Ferrous Metals, with Special Reference to the Use of the Quantometer*," by A. Argyle—39 Elmbank Crescent, Glasgow, 6.45 P.M.

23rd Nov.—SHEFFIELD METALLURGICAL ASSOCIATION—"*Chemical Analysis: Some Physical-Chemical Considerations*," by C. E. A. Shanahan—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 P.M.

23rd–25th Nov.—SCIENTIFIC INSTRUMENT MANUFACTURERS' ASSOCIATION—Exhibition: "*Electronics at Work*"—Chamber of Commerce Hall, Birmingham.

24th Nov.—INSTITUTE OF METALS (Sheffield Local Section) (Joint meeting with Sheffield Society of Engineers and Metallurgists and the Yorkshire Branch of the Institution of Mechanical Engineers)—"*High-Temperature Water-Cooling of Open-Hearth Furnaces by Means of Steam-Producing Elements*," and "*The Cooling of Large Rolling Mill Drives*," by F. J. Feltoe and P. Moreton—Mappin Hall, Sheffield, 6.30 P.M.

24th Nov.—MANCHESTER METALLURGICAL SOCIETY—"*Some Experiences in Industrial Research*," by B. P. Dudding—Lecture Room, Central Library, Manchester, 6.30 P.M.

25th Nov.—INSTITUTE OF METALS (Birmingham Local Section)—"*The Working of Metals*," by J. G. Wistreich—James Watt Memorial Institute, Great Charles Street, Birmingham, 6.30 P.M.

25th–26th Nov.—INSTITUTE OF METALS—General Meeting—4 Grosvenor Gardens, London, S.W.1.

30th Nov.—SHEFFIELD METALLURGICAL ASSOCIATION—Discussion on Open-Hearth Furnaces: Acid Roofs—B.I.S.R.A., Hoyle Street, Sheffield, 3, 7.0 P.M.

1st–2nd Dec.—THE IRON AND STEEL INSTITUTE—Symposium on Powder Metallurgy—Church House, Westminster, London, S.W.1.

2nd Dec.—INSTITUTE OF METALS (Joint meeting with the Chemical Engineering Group of the Society of Chemical Industry)—"*Thermochemistry of Alloys*," by A. R. Harding—University Chemical Department, Woodland Road, Bristol, 6.30 P.M.

2nd Dec.—EBBW VALE METALLURGICAL SOCIETY—"*The Effects of Some Metallurgical Factors on the Development of Hydrogen Swells in Cans Made from Electrolytic Tinplate*," by E. Morgan.

TRANSLATION SERVICE

(The previous announcement was made in the October, 1954, issue of the *Journal*, p. 188.)

TRANSLATIONS AVAILABLE

No. 492 (German). H. WIRTZ: "The Sampling of Ferro-Alloys and their Ores." (*Archiv für das Eisenhüttenwesen*, 1954, vol. 25, May–June, pp. 225–230).

TRANSLATIONS IN COURSE OF PREPARATION

No. 493 (German) A. KEIL: "Should One Use Solid or Segmented Resin Bearings in Rolling Mills?" (*Die Technik*, 1953, vol. 8, Sept., pp. 609–612).

(Polish). G. KNIAGININ: "Influence of Steel Casting Design on Internal Stress." (*Przeglad Odlewnictwa*, 1953, vol. 3, No. 12, pp. 341–346).

(Swedish). B. THYBERG: "Hot-Blast Cupolas." (*Gjuteriet*, 1954, vol. 44, Feb., pp. 19–28.)

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

CONTENTS

	PAGE
FUEL—PREPARATION, PROPERTIES AND USES	311
TEMPERATURE MEASUREMENT AND CONTROL	312
REFRACTORY MATERIALS	312
BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON	313
PRODUCTION OF STEEL	315
FOUNDRY PRACTICE	318
HEATING FURNACES AND SOAKING PITS	321
HEAT-TREATMENT AND HEAT-TREATMENT FURNACES	321
FORGING, STAMPING, DRAWING, AND PRESSING	321
ROLLING-MILL PRACTICE	322
MACHINERY FOR IRON AND STEEL PLANT	323
LUBRICANTS AND LUBRICATION	323
WELDING AND FLAME-CUTTING	323
MACHINING AND MACHINABILITY	324
CLEANING AND PICKLING	324
PROTECTIVE COATINGS	325
POWDER METALLURGY	327
PROPERTIES AND TESTS	327
METALLOGRAPHY	329
CORROSION	331
ANALYSIS	332
ECONOMICS AND STATISTICS	333
MISCELLANEOUS	334
BOOK NOTICES	334
NEW PUBLICATIONS	335

FUEL—PREPARATION, PROPERTIES, AND USES

Dry Coal Cleaning Plants. J. Findlay. (*Queensland Gov. Min. J.*, 1954, **55,** Jan. 20, 13–17). A description is given of the operation of a Saxon separating plant designed to clean up to 50 tons/hr. of raw coal. These plants are manufactured by the Saxon Engineering Coy., Ltd., Stoke-on-Trent.

The Coal Washing Plant at West Bokaro, India. (*Min. J.*, 1954, **242,** Apr. 24, 475–477: *Iron Coal Trades Rev.*, 1954, **168,** May 21, 1189–1192).

Theoretical Basis and Practical Execution of the Tests Employed to Define the Working of the Apparatus Used for Cleaning Crude Coal. F. Pintado Fe. (*Inst. Nac. Carbon, Bol. Inf.*, 1953, **2,** Nov., 23–28). [In Spanish]. Coal is divided into 'washed' and 'mixed' categories. Curves of washability as functions of densities are described. Other curves indicating the amounts of various sub-constituents are also presented.—C. B. L.

Solid Fuel Firing of Metallurgical Furnaces: Use of Pulverized Fuel. (*Iron Coal Trades Rev.*, 1954, **168,** Apr. 30, 1019–1023, 1026). Reference is made to some of the successful applications of pulverized fuel to metallurgical furnaces, ranging from the relatively low-temperature heat-treatment furnaces to the higher-temperature furnaces used for melting iron and steel. The advantages of this type of firing are discussed.—G. F.

John Summers & Sons Limited—Coking Plant. (*Iron Coal Trades Rev. Special Issue*, 1953, Apr. 20, 16–23). The new coke-oven plant of John Summers & Sons Ltd. consists of duplicate batteries of 88 ovens each, with a capacity of 3060 tons of dry coal per day. Details are given of the design and operation of the ovens, the coal and coke handling plants, and considerable attention is also given to the by-product plant.—G. F.

Battery of New Coke Ovens Put in Operation by Bethelem Steel Co. (*Indust. Heating*, 1954, **21,** Mar., 500–502). Details are given of a new installation which utilizes the new 'saddleback' refractory brick liners, improved doors and door moving equipment, and electronic controls.—R. W. B.

The Production of Coke to Blast-Furnace Specifications. J. A. Beatty. (*Blast Furn. Steel Plant*, 1954, **42,** Mar., 339–344). The coke-oven practice at the Bethlehem plant of the Bethlehem Steel Co., U.S.A., is described in detail; particular attention being paid to the coal blending equipment.—B. G. B.

On the Resumption of Kukioka No. 1 Coke Oven. S. Haseba. (*Tetsu to Hagane*, 1951, **37,** Jan., 2–13). [In Japanese]. The battery was closed down as a result of air raids, and left for three years. For resumption of operations, no renovations were made to cracks in the oven body or brick bonding, or to the regenerators. Details of drying and heating up with blast-furnace gas, are given.—K. E. J.

Metallurgical Coke from Blends. J. Roberts. (*Coke Gas*, 1954, **16,** Mar. 113–116). Recently published data on the carbonization of blends of feebly coking and normal coking coals are discussed, together with the use of cinder coal mixed with coking coal. The author recommends that the blended coke should be given extensive tests in blast-furnaces.

Measurement of Gas Pressure within the Coal Charge in Coke Ovens. C. C. Russell, M. Perch, and H. B. Smith. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn. Coke Oven Raw Mat. Comm.*, 1953, **12,** 197–215). A practical method of measuring gas pressures in a coking coal charge has been developed and is described. Many tests in a movable wall oven have shown the character and magnitude of the gas pressures developed and a relationship between peak wall pressure and centre gas pressure has been obtained.

Present and Future Aspects of Carbonization Research. H. W. Nelson and J. J. Ward. (*Amer. Inst. Min. Met. Eng., Proc. Blast Furn. Coke Oven, Raw Mat. Comm.*, 1953, **12,** 182–197). A short account of recent research work in the coal carbonization field is presented and subjects requiring further study are suggested. (35 references).—B. G. B.

Recording Instrument for Following the Destructive Distillation of Solid Fuels. H. Echterhoff. (*Glückauf*, 1954, **90,** Mar. 13, 318–321). An apparatus is described in which the loss in weight of a solid fuel is recorded in relation to the time of heating. The rise in temperature is controlled to a constant rate. Experiments on various types of coal are described, and the results discussed.—L. D. H.

Size Analysis of Coke. A. B. Manning. (*Coke Gas*, 1954, **16,** Mar., 104–106). The problems of coke sampling for size grading are discussed and the statistical bases of the recommended method given in British Standard B.S. 2074 : 1954, are explained.—B. C. W.

On the Reactivity and Formation Mechanism of Metallurgical Coke. S. Kiuchi. (*Tetsu to Hagane*, 1951, **37,** Mar., 140–144). [In Japanese]. Remarkable differences in combustion velocities were found for cokes and anthracite, although their activation energies were very similar. This anomaly is explained by consideration of the frequency factor of burning carbon aggregates. The reactivity, hardness, and strength of coke can similarly be explained in terms of growth of carbon grains.—K. E. J.

Reactivity of Cokes. M. R. Egalon, M. J. Hoebeke and M. F. Jarcsek. (*Mém. Soc. Ing. Civils France*, 1953, May–June, 249–290). An investigation into the properties of coke

has been carried out in order to try to find a physico-chemical test to distinguish between good and bad cokes. Among the tests examined were X-ray powder diffraction, the B.E.T. adsorption method and the measurement of the density with helium ; but these were not found suitable. A method of measuring the reactivity to oxygen, carbon dioxide and water vapour has been developed and is described in detail. Results obtained with this apparatus on a large number of cokes and carbons are given and discussed.—B. G. B.

Comparison between the Two Types of Gas Purification Using Liquids. L. Taubert and J. Morlet. (*Chim. et Ind.*, 1954, **71,** Feb., 273–276). The currently employed liquid purification processes fall into two categories—those of absorption–desorption in an alkaline solution, and those of oxidation–reduction. The efficiency of the two processes is compared and the importance of secondary reactions is stressed. The choice of process depends on the result desired.—A. G.

Usco's New Gas Producer Starts Production. (*Usco Mag.*, 1954, **5,** Jan., 8–12). A description is given of South Africa's modern and largest, single industrial gas plants which recently started production at the Klip Works. The plant consists of seven Wellman-Galusha producers 10 ft. in dia., each capable of gasifying one ton/hr. of anthracite coal. Two producers are connected to a cooling and scrubbing plant. The other four producers will supply the furnaces in the steel-producing plant and the rolling-mill furnaces in the wireworks. One producer is in reserve.—L. E. W.

Gas Producer Control: A Fully Automatic System. (*Iron Steel*, 1954, **27,** Feb., 48). A brief description is given of a fully automatic gas producer control system developed jointly by George Kent Ltd. and the British Coal Utilisation Res. Assoc. The system includes control of gas off-take pressure and temperature, and of blast saturation temperature, with automatic regulation of coal feed.—G. F.

Long-Distance Gas Supply in Western Germany. C. Schemmann. (*IVA.*, 1953, **24,** Aug., 104–111). [In German]. Gas supplied for public use in Germany is obtained by the coking process. Corrosion of pipes is minimized by 'preventing condensation. Welded steel pipes have proved efficient for its conveyance.—R. P.

TEMPERATURE MEASUREMENT AND CONTROL

A Phototube Measuring Circuit for Thermopiles. R. K. Brinton and C. T. O'Konski. (*Rev. Sci. Instruments*, 1953, **24,** Dec., 1102–1104). A circuit is described for measuring the e.m.f. generated by a slow response linear-type thermopile, in which a feed-back circuit, which keeps the galvanometer at its zero-signal position is proportional to the thermopile signal, and an auxiliary circuit compensates for drift.—L. D. H.

Thermocouples. G. Lindholm. (*Tekn. Tidskr.*, 1954, **84,** Apr. 6, 307–309). [In Swedish]. To help avoid errors commonly made as a result of incorrect choice of thermocouple material or design, the author gives hints on the temperature ranges of the various elements, optimum wire thickness and insulation, permissible variations in e.m.f. curve, tolerances for compensating leads, sheath design, and installation.

Design for an Embedded Thermocouple—Steamtight Units for Plates, Tubes or Drums. D. E. Upton. (*Engineering*, 1954, **177,** Apr. 16, 489). A mineral-insulated base-metal thermocouple wire contained in a metal sheath and commercially available is described. This type of thermocouple is particularly suitable for use in confined space, such as the interior of a superheater tube.—M. D. J. B.

Deterioration of Selenium Photo Cells of the Barrier Layer Type. G. A. Veszi. (*Instrument Practice*, 1953, **7,** Dec., 1173–1174). After outlining the causes leading to deterioration of selenium barrier layer type photocells, the author describes the Megatron type " B " cell, which has a top electrode of cadmium oxide. The oxide layer shows interference patterns, changes in which indicate alterations in the layer. Effects of mechanical and chemical attack on the oxide are described.—L. D. H.

Recent Progress in Automatic and Remote Control by Electro-Pneumatic Action. V. Broida. (*Chim. Analy.*, 1953, **35,** Dec., 291–302). The fundamentals of pneumatic and electrical controllers are outlined and the advantages and disadvantages of each type considered. It is pointed out that by combining both principles into an electro-pneumatic controller considerable advantages may result. A number of commercially available electro-pneumatic temperature controllers are discussed in detail.—B. C. W.

The "Milliskope," An Objective Disappearing Filament Pyrometer for Temperature Determinations with no Lag. F. Marchevka. (*Draht, German ed.*, 1954, **5,** Mar., 96–98). The 'Milliskop', manufactured by P. F. Peddinghaus in co-operation with Hartmann and Braun, A. G., is described and illustrated. Reference is made to its application in a flame-hardening machine.—J. G. W.

REFRACTORY MATERIALS

Some Notes on Kyanite. G. Marceau. (*Écho Mines*, 1954, Feb., 101–103). A short account of the known deposits of this anhydrous aluminium silicate and the uses to which it is put is given. It is a raw material for the production of refractory bricks.—B. G. B.

Kyanite in Canada. V. A. Haw. (*Trans. Canad. Min. and Met.*, 1954, **47,** Jan., 25–33 ; *Bull.*, 27–35). Large deposits of grades up to 30% have been discovered particularly in the Sudbury area. Crushing and concentration trials are described. The uses of kyanite and its future demand are discussed in relation to the establishment of a kyanite industry in Canada.—A. G.

High-Temperature Phase Change in Kaolinite. W. D. Johns. (*Mineralogical Mag.*, 1953, **30,** Sept., 186–198). New data relating to high-temperature forms of kaolinite are presented and structural relationships between kaolinite, metakaolinite and millite are discussed. A mechanism of thermal and crystallographic changes involved in phase transformation is suggested.—E. C.

Refractory Materials in South Africa. (*Min. J.*, 1954, **242** May 4, 576–577). A short account is given of the recent advances in the processing and development of raw refractory materials in South Africa. The refractories include fireclay, silica, high alumina chrome-magnesite, dolomite, and vermiculite materials.—B. G. B.

The Grain Controlling of Silica Brick. Y. Inamura. (*Tetsu to Hagane*, 1951, **37,** May, 266–272). [In Japanese]. Methods of grain size control are described. Silica bricks made from grains of selected size exhibit low porosity, high resistance to spalling and abrasion, and high viscosity when molten ; they are therefore suitable for roofs of open-hearth and electric furnaces, and for rotary kilns.—K. E. J.

Reproducibility in the Refractoriness-under-Load Test. A. H. B. Cross. (*Trans. Brit. Ceram. Soc.*, 1954, **53,** Mar., 77–94). An investigation into the reproducibility of the refractoriness-under-load test is described ; three types of brick were used. A description of the equipment is given, and the results detailed and discussed. Finally, a simple electrical recording dilatometer is described.—D. L. C. P.

The Influence of Heating Rate on the Refractories-under-Load of a Firebrick. A. H. B. Cross. (*Trans. Brit. Ceram. Soc.*, 1954, **53,** Mar., 95–102). A series of rising-temperature load tests is reported, the object being to assess the effect of different rates of heating above 1000° C. Using specimen $1\frac{3}{4}$ in. square and $2\frac{1}{2}$ in. high, a heating rate of 10° C./min. was too high above 100–150° C. below the temperature at which the brick commenced to subside. A rate of about 2° C./min. is preferable to obtain uniformity in the test piece.

A New Thermal Conductivity Apparatus for Refractory Materials. J. F. Clements and J. Vyse. (*Trans. Brit. Ceram. Soc.*, 1954, **53,** Mar., 134–155). A new apparatus for the measurement of thermal conductivity of refractory materials at high mean temperatures is described, and sources of error in the apparatus analysed in detail. Finally, some measurements made with the apparatus are presented.—D. L. C. P.

A Co-operative Test on Thermal Conductivity. A. F. Watson. J. F. Clements, and J. Vyse. (*Trans. Brit. Ceram. Soc.*, 1954, **53,** Mar., 156–164). The thermal conductivities of a high temperature insulating brick and a fused-alumina brick were both measured by (*a*) the A.S.T.M. method in one laboratory, and (*b*) the Brit. Ceram. Res. Assoc. method in another, and the methods and results compared. It is concluded that both methods give results within ±5% of the true conductivity.

Contact Angle Measurements of Slags on Solid Surfaces. H. Towers. (*Trans. Brit. Ceram. Soc.*, 1954, **53,** Mar., 180–202). The surface energy factors influencing reaction between liquid slag and solid refractory are discussed. A technique for measuring contact angle continuously at high temperatures has been worked out and results are given for various

slags on platinum and alumina, the effect of atmosphere being noted. The change in contact angle between slag and graphite with time was studied.—D. L. C. P.

The Quaternary System CaO–Al_2O_3–TiO_2–SiO_2. Part II—The Ternary System Calcium–Metasilicate–Sphene–Silica. Part III—The Quarternary System Calcium–Metasilicate–Anorthite–Sphere–Silica. Y. M. Agamawi and J. White. (*Trans. Brit. Ceram. Soc.*, 1954, **53,** Jan., 1–38). The fact that when a silcrete brick in service has picked up lime, its composition will lie in the quarternary volume calcium-metasilicate—anorthite–sphene–SiO_2, led the authors to investigate the thermal–equilibrium diagram of this system. The isoplethal method of study, using the quenching technique was employed. The equilibrium phases were identified by microscope and X-ray examination. Results are shown and discussed and diagrams of the systems given. The ternary system was of a simple eutectic type and the quaternary eutectic point of the quarternary system was located.

Additional Phase Equilibrium Data for the System CaO–MgO–SiO_2. R. W. Ricker and E. F. Osborn. (*J. Amer. Ceram. Soc.*, 1954, **37,** Mar., 133–139). A revised equilibrium diagram for the system is presented incorporating the latest information, including new data obtained from experiments which are described. At or near liquidus temperatures solid solution between forsterite and monticellite is extensive. In the low silica region a field of tri-calcium silicate has been outlined, and approximate liquidus temperatures determined.

Alumino–Silicate Refractories: Some Observations on Their Chemistry. E. C. Shears. and W. A. Archibald (*Iron Steel*, 1954, **27,** Jan., 26–30 ; Feb., 61–66). The authors outline the development of the chemistry of the alumino-silicates, showing the relationships among the structures of andalusite, kyanite, sillimanite, and mullite. Only mullite is usually produced when Al_2O_3 and SiO_2 are heated together at normal pressure; its stability in contact with other oxides is discsused. A revision of the $Al_2O_3.SiO_2$ diagram is suggested, with a solubility gap covering mullite compositions from 3 Al_2O_3.2 SiO_2 to 2 Al_2O_3. SiO_2 at low temperatures, the latter composition being formed in the peritectic reaction. (64 references).

Refractories in the Steel Industry. K. W. Slack. (*E.S.C. News*, 1954, **7,** Spring, 2–7). The author discusses the wide range of refractory materials used in the steel industry, how they originate, and how they are treated before delivery. The successful solutions of a few refractory problems are mentioned and a table of the common steelworks refractories, their softening points, applications, and outstanding properties, is included.—L. E. W.

New Materials of Construction for Heat Engines in High Temperature Service. B. L. Majumder. (*Sci. Eng.*, 1953, **6,** Mar.-Apr., 33–39). The properties of ceramic materials developed for gas turbine blades (including zirconia, beryllia, sillimanite, boron carbide, titanium carbide, and magnesia) are reviewed. (36 references).—R. A. R.

Zircon and Zirconia—Versatile Materials for the Ceramic and Allied Industries. W. L. German. (*Ceramics*, 1954, **5,** Feb., 540–544). Properties and uses of the materials are reviewed. Zirconia is reported as having formed a good hearth in an electric steel melting furnace, and zirconia washes have shown resistance to coal-ash slags.—D. L. C. P.

Scientific Approach to New Ceramics. W. J. Kramers. (*Research*, 1954, **7,** Mar., 101–110 ; Apr., 142–151). The term ' ceramic ' now includes manufactured shapes of all types of polycrystalline compounds. There is a growing demand for ceramic materials for use in fabrication and process metallurgy, for electrical devices, and as substitutes for metals in components required to withstand stress at high temperatures. Fundamental research has been markedly successful in the electrical industry. The application of knowledge of the physics and chemistry of the solid state to the development of new ceramics is examined. The inorganic chemical field available is very large. Large scale preparation is possible for materials intermediate between metals and normal metallic compounds. The physical bases of the important properties, and means of controlling them, are surveyed. (149 references).—K. E. J.

Development of Open Hearth Roof Refractories in Great Britain. (*Indust. Heating*, 1954, **21,** Jan., 145–146). Brief reference is made to the capabilities of low alumina and titania silica bricks and to ' Silcrete.' The principal advantages of the latter are attributed to its porosity and density.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Blast-Furnace Controls. (*Tecn. Met.*, 1953, **9,** Aug., 282–283). [In Spanish]. This short article contains a diagram of blast-furnace and stoves in which are indicated the points at which pressures, flow, mixing, temperature, height of stock-line, and gas analysis can be metered or controlled. Thirty items are listed in the plan for recording points.—R. S.

Pressure Operation Grows in European Blast-Furnace Practice. E. L. Pepper. (*Iron Age*, 1954, **173,** Jan. 28, 128–132). Claims of increased output together with reduced coke consumption and less flue dust are made. The ability to use low-grade ores and cokes is also stressed. The only furnace actually working on high top pressure in western Europe is that of Colvilles Ltd. although it is known that a number of others have been constructed or modified for this purpose. The low shaft furnace at Liége aud the use of axial blowers are also described.—A. M. F.

The Rebuilding of Four Blast Furnaces at the Salzgitter Iron and Steel Works. W. Ingernerf. (*Stahl u. Eisen*, 1954, **74,** May 6, 649–651). The techniques and the newer methods of construction and cooling employed in the rebuilding of these furnaces are briefly described and illustrated.—J. P.

Progress of the Blast-Furnace Operation in Japan To-Day. K. Wada. (*Tetsu to Hagane*, 1954, **40,** Feb., 128–141). [In Japanese].

Some Special Operations of the Wanishi-Machi No. 3 Blast Furnace. T. Onoda and K. Kusuno. (*Tetsu to Hagane*, 1951, **37,** Nov., 551–554). [In Japanese]. On a small blast-furnace with excess blowing capacity, interesting results from common blowing operation are recorded. During single furnace operation with poor coke (55% drum index), the best output was obtained by increasing the ore/coke ratio, increasing blast pressure, and enlarging the tuyeres to increase blast volume.

How to Reduce the Blast-Furnace Coke Rate. P. Morcinek. (*Hutnâk*, (Prague), 1954, **4,** (3), 67–70). [In Czech]. The manner in which ore preparation, rate and method of charging, and the dimensions of the furnace influence coke consumption are discussed, and the factors making for an optimum coke rate, such as correct thermal balance, grading and sintering of agglomerates, quality of primary slags, coke quality, blast temperature, and oxygen and steam enrichment of the blast are considered.—P. F.

A New Type of Automatic Blast-Furnace Charging Control. E. H. Abbe. (*Blast Furn. Steel Plant*, 1954, **42,** Apr., 424–427). A description is given of new automatic charging equipment fitted to a blast-furnace at the Midland, Pennsylvania, plant of the Crucible Steel Company of America. About 3000 tons of material/day are loaded into the furnace. The equipment consists of the electrical control for the drives of the various mechanical parts of the loading system and a programme control which provides for the interlocking and timing of the various drives for the automatic control of the charging cycle.—B. G. B.

Cyclones for Cleaning Blast-Furnace Gas. M. Havelka. (*Hutnické Listy*, 1954, **9,** (3), 131–140). [In Czech]. The use of iron ores of small particle size and the attendant increased rate of reduction in the blast-furnace results in a high dust content in the flue gases which cannot be reduced sufficiently by conventional dust catchers. By inserting cyclones into the gas stream after the dust collectors most of this iron-rich dust can be recovered. The design of cyclones, and their efficiency and mode of operation are examined, and details of their use in Czechoslovak steelworks for blast-furnace gas cleaning are given. Results of works experiments, relating the dimensions of cyclones, gas velocity, pressure loss, and the nature and quantity of dust separated are discussed.

Blast-Furnace Gas. I—Properties and Uses of Blast-Furnace Gas. II—Pipelines for Crude and Cleaned Gas. J. Szczeniowski. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, " *Les Cahiers du CESSID* " *No.* IV, pp. 29). The physical, chemical and thermal properties of blast-furnace gas are outlined and a comparison is made with other fuels. The problems of preheating, storage, and transport are considered. In modern boiler plants the gas can be burnt with 85% efficiency. Other uses include reheating furnaces, gas engines, and as mixed gas. Crude gas pipelines are discussed in relation to their basic functions of primary cleansing and safe transport with a minimum pressure drop. The auxiliary equipment of clean gas pipelines including explosion valves, pressure

controllers and purge pipes, is described. Finally, the rôle of the distributing section in ensuring a safe pressure of gas and regulating the distribution of gas accordingly is considered.

Blast-Furnace Gas. IIIa—Wet Cleaning. P. Mellet. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahiers du CESSID*" *No.* IV, pp. 33). The mechanism of wet gas cleaning and results attainable are outlined. Disintegrator plant is described and its advantages and disadvantages are considered. The Ventil and Venturi wet-cleaning systems are also dealt with and the problem of the treatment of washing water by such methods as decantation is discussed.—A. G.

Blast-Furnace Gas. IIIb—Dry Cleaning. J. Szczeniowski. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahiers du CESSID*" *No.* IV, pp. 23). The preliminary treatment of crude gas, various methods of dry cleaning control installations and the personnel necessary are discussed. The high moisture content of the exit gas makes refrigeration before use beneficial. The results achieved are considered in relation to the capital cost and the proceeds from the sale of gas.—A. G.

Blast-Furnace Gas. IIIc—Electrostatic Cleaning. H. Meynadier. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahiers du CESSID*" *No.* IV, pp. 26). After a theoretical account of the principles involved, a dry electrostatic cleaning plant is described and operating conditions and results are given. The possible variations, including one stage electro filters and mixing equipment, are discussed.—A. G.

Blast-Furnace Gas. IV—Comparison of Different Gas Cleaning Systems. A. Boitel. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahiers du CESSID*" *No.* IV, pp. 23). The principles of the various gas-cleaning systems and the plant required are discussed together with the efficiency and degree of cleaning possible for each method. Unless very high purity gas is required, the choice of system depends on the availability of water and cheap electricity, wet washing being preferable.—A. G.

Blast-Furnace Gas. V—Gas and Energy Balance of an Iron and Steel Works. J. Szczeniowski. (*IRSID, Centre d'Etudes supérieures de la Sidérurgie*, Metz, 1953, "*Les Cahiers du CESSID No.* IV, pp. 32). A detailed gas and energy balance is presented for an integrated iron and steel works. Methods of achieving the minimum consumption in energy of transformation to different states are considered. Modern tendencies in iron and steel production result in a decrease in the consumption of coke per ton of finished product and an increased use of electricity.—A. G.

The Behaviour of Sulphur in Silicate and Aluminate Melts. C. J. B. Fincham and F. D. Richardson. (*Proc. Roy. Soc.*, 1954, **A223**, Apr. 7, 40–62). A study was made of the manner in which sulphur is held in the melts, using $CaO–SiO_2$, $MgO–SiO_2$, $FeO–SiO_2$, $CaO–Al_2O_3$, and $CaO–SiO_2–Al_2O_3$ mixtures between 1350 and 1650° C. Two mechanisms (sulphide and sulphate formation) are described and sulphur capacities are derived. The results are used to provide free energy and heat of formation information. The sulphur capacities of ternary $CaO–SiO_2–Al_2O_3$ melts were also investigated. (38 references).

Retarding Effect of Gaseous Reaction Products on the Rate of Reduction of Iron Oxide by Hydrogen and Carbon Monoxide. G. I. Chufarov, B. D. Averbukh, E. P. Tatievskaya, and V. K. Antonov. (*Zhurnal Fizicheskoĭ Khimii*, 1954, **28**, (3), 490–497). [In Russian]. An investigation is described on the effects of CO_2 and water on the rates of reduction of iron oxides by CO and hydrogen, respectively. The experiments were made at a pressure of 100–250 mm. Hg, and the adsorptions of the gaseous reactants aud resultants on the iron oxides were also determined. An equation for rate of reduction of Fe_3O_4 and FeO by CO in terms of the actual and equilibrium partial pressure of CO and the actual partial pressure of CO_2 is given. Above 700° C. the reduction of Fe_2O_3 by CO and by hydrogen was retarded by the reaction products only when the degree of reduction was over 11%. The kinetic and adsorption data obtained were in good agreement.—S. K.

On the Solubility of Iron in Liquid Slags. P. M. Shurygin and O. A. Esin. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **95**, (5), 1043–1045). [In Russian]. The authors found that a drop of gold placed into molten $FeO–Fe_2O_3$ slag contained metallic iron after quenching. A similar transfer of iron from Fe_2SiO_4 slag into copper was also observed. The authors' experiments showed that iron is present as an atomic solution in liquid slags. Experimental data showed that the equilibrium iron content transferred into gold, at a given temperature, increases with an increase in the ratio $(\%Fe^{2+})^3/(\%Fe^{3+})^2$.

Manganese in Ferrous Metallurgy. (*Usine Nouvelle*, 1953, **9**, Dec. 10, 29–31; Dec. 31, 24–25). Consumption of manganese is estimated to rise from 1·8 million tons in 1950 to 2·7 million tons in 1975. Economy in its use is therefore very important. It is suggested that manganese should be added to the blast-furnace as low grade ore or open-hearth slag, conserving the richer ore for the production of ferromanganese. The processes employed in various European countries for the recovery of manganese from fumes and slags are described.

Distribution of Manganese Between Slag and Metal Under Reducing Conditions. J. E. Stuckel and J. Cocubinsky. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**; *J. Met.*, 1954, **6**, Mar., 353–356; *Blast Furnace, Coke Oven, and Raw Materials Conf.*, 1952, **11**, 124–137). The authors have investigated the equilibrium distribution of manganese between blast-furnace type slags and carbon-saturated iron under reducing conditions, using a graphite crucible in a small induction furnace. The results show that the distribution approaches equilibrium values in the blast furnace, being little-affected by alumina content of the slag or by substitution of up to 13% MgO for CaO, and confirm that manganese recovery is enhanced by high CaO/SiO_2 ratios, high temperatures, and low slag volumes.—G. F.

Chromium Distribution Between Liquid Iron and Molten Basic Slags. N. J. Grant, E. C. Roberts, and J. Chipman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**; *J. Met.*, 1954, **6**, Feb., Section 1, 145–149). The authors have made an equilibrium study of the distribution of chromium and oxygen between liquid iron, containing less than 1% Cr, and slags of the $CaO\ (MgO)–SiO_2–FeO–Cr_2O_3$ type in the temperature range 1526–1734° C. The effects of slag oxidation, temperature, and basicity have been observed, and the results are presented and discussed.—G. F.

On the Equilibrium among Silicon in Molten Iron, Molten Slag, and $H_2–H_2O$ Mixed Gas. (II). K. Sanbongi and M. Otani. (*Tetsu to Hagane*, 1951, **37**, Sept., 462–468). [In Japanese]. Results of equilibrium measurements in the range 1550–1650° C. are presented for the reaction $(SiO_2)CaO + SH_2 \rightleftharpoons [Si] + 2H_2O$, and the activity of CaO was deduced.—K. E. J.

Effects of Some Catalysers on Reduction Velocity of Solid Iron Oxide by Carbon. H. Susukida and K. Sano. (*Tetsu to Hagane*, 1951, **37**, Sept., 456–461). [In Japanese]. It was shown that $BaCO_3$ catalyses the reaction $C + CO_2 \rightarrow 2CO$, and CaO the direct and indirect reduction of Fe_2O_3. MgO, TiO_2, Al_2O_3 and SiO_2 are negative catalysts in the reduction of Fe_2O_3.—K. E. J.

One Experiment on the Desulphurizing Action of Lime. T. Uno. (*Tetsu to Hagane*, 1951, **37**, Jan., 14–17). [In Japanese]. Equilibrium data in the temperature range 1000–1100° C. are presented for the reactions $CaO + H_2S = CaS + H_2O$ and $CaO + \frac{1}{2}S_2 = CaS + \frac{1}{2}O_2$.—K. E. J.

Desulphurizating Action of Lime. T. Uno. (*Tetsu to Hagane*, 1951, **37**, Feb., 78–80). [In Japanese]. The equilibrium constants and their temperature coefficients were obtained for the reactions CaO + FeS (in Fe) = CaS + FeO (liq.) and CaO + FeS (in Fe) + C (in Fe) = CaS + Fe (liq.) + CO.—K. E. J.

The Step-Wise Nature of the Thermal Dissociation Process of Siderites. V. I. Kaurovskiĭ. (*Zhurnal Prikladnoi Khimii*, 1954, **27**, (2), 136–141). [In Russian]. In the investigation described the thermal decomposition of siderites was studied by differential thermal analysis. Two siderite ores were used having the respective percentage compositions: Water 0·30, 0·41; loss on ignition 29·97, 31·04; SiO_2 4·60, 4·24; Fe_2O_3 2·91, 2·60; FeO 54·75, 51·89; Al_2O_3 2·54, 2·57; Mn_2O_3 0·41, 0·46; CaO 1·80, 2·92; MgO 0·80, 1·65; P_2O_5 0·28, 0·46; SO_3 0·23, 0·94; CO_2 21·91, nil; total alkali 0·53, nil. The specimens were contained in cells limiting the ingress of air. The differences in the shapes of curves obtained are related to the microstructures of the siderites. Their thermal decomposition is said to be a multi-stage process governed mainly by the crystal structure.—S. K.

Experiences in Salamander Tapping. C. M. Squarcy and E. H. Bare. (*Blast Furn. Steel Plant*, 1954, **42**, Mar., 331–335). An account is given of the experience gained during tapping of salamanders in four furnaces of the Inland Steel Co., U.S.A. Details of the furnace construction and the methods used to drill into the furnaces are reported.—B. G. B.

PRODUCTION OF STEEL

Contribution to the Problem of Pig Iron and Steel Production and Desulphurization. A. Děkanovský. (*Hutnické Listy*, 1954, **9**, (4), 195–203). [In Czech]. The increasing emphasis on the use of the abundant Czechoslovak lean and acid iron ores demands a reassessment of methods of iron and steel production. The most important problem is that of efficient desulphurization of pig iron, and the principal methods such as those utilizing anhydrous sodium carbonate, lime, calcium carbide, synthetic slags, and magnesium are discussed. The use of lean ores and shortage of scrap render the open-hearth furnace less economical than reduction of the ore in a rotary furnace of the Krupp-Renn type, followed by melting in a cupola or other melting furnace, or also in a low-shaft blast furnace working with oxygen. The resulting pig iron is quickly and economically convertible into steel in converters blown with oxygen-enriched air, or in the downward blown converter as used at the Linz-Donau Works. Desulphurization of pig iron or steel is possible in this process.—P. F.

Presidential Address. D. L. Blewett. (*Swansea Met. Soc.*, Oct. 17, 1953). The author deals broadly with the economic, sociological and technological aspects of the steel industry. Attention is drawn to some of the important considerations in the selection of fuel, to the advantages derived from the use of oil fuel, and to methods of ensuring fuel efficiency. Sound metallurgical practice in the melting shop, casting pit, and bar mill, is discussed. Some of the vital factors in planned steelworks maintenance are introduced and the need for friendly relations between supervisors and operatives is stressed. The proper training of all personnel is recommended.—L. E. W.

United States Steel in the West. J. L. Young and W. F. Pruden. (*Iron Steel Eng.*, 1954, **31**, Apr., 55–64). The authors make a comprehensive review of the United States Steel Corp. activities in the Western States of the U.S.A. These have increased 400% since 1943. The ironmaking, steelmaking, rolling and engineering divisions are described and details are given of layout, plant, and production.

John Summers & Sons Limited—Planning for the New Developments. (*Iron Coal Trades Rev., Special Issue*, 1953, Apr. 20, 7). A brief summary is given of the programme for the recent extensions of the Shotton works of John Summers & Sons Ltd.—G. F.

John Summers & Sons Limited.—Historical Background. (*Iron Coal Trades Rev., Special Issue*, 1953, Apr. 20, 8–10, 23). This article traces the history and development of John Summers & Sons Ltd., and recalls some of the early personalities associated with the firm.—G. F.

John Summers & Sons Limited.—Preparation of the Site. (*Iron Coal Trades Rev., Special Issue*, 1953, Apr. 20, 11–15). The preparation of the site for the extensions at John Summers & Sons Ltd. involved considerable land reclamation accomplished by hydraulic fill. An illustrated account of the work is given.—G. F.

John Summers & Sons Limited—Steelmaking Plant: Design and Operation. (*Iron Coal Trades Rev., Special Issue*, 1953, Apr. 20, 46–60). The complete new steelplant at John Summers & Sons Ltd. consists of the melting shop, raw materials building, and lime and dolomite plant. An outline is given of the layout and objects of the lime and dolomite plant and of the raw materials building, followed by a detailed description of the melting shop with its eight 150-ton open-hearth furnaces. In addition to the furnaces, attention is given to their instrumentation, crane equipment, safety devices, waste-heat boilers, casting ladles, casting bay, and stock bay.—G. F.

Selection of Procedures for the Production of Steel and for the Location of Integrated Plants for Producing Iron and Steel. W. A. Haven. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.52). [In Spanish]. Descriptions are given of the types of plant set up at Volta Redonda in Santa Catarina State, Brazil, and in Boyacá State, Colombia. Details are given of the local minerals and the special adaptations which their treatment involved. Four sketch maps are given.—C. B. L.

Comparative Investment Costs for Different Steelmaking Processes. Ramseyer and Miller, Inc. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.53). [In English]. A study is presented of the relative capital investment requirements of plants for the production of steel ingots by six major steel making processes *i.e.*, the acid and basic Bessemer ; basic open-hearth ; electric furnace ; the acid-Bessemer/basic open-hearth duplex process ; and the acid-Bessemer/basic electric furnace duplex process.—V. G.

Approximate Comparative Production Costs and Investment Requirements of the Standard Blast Furnace, Electric Smelting Furnace, Sponge Iron Furnace and Tunnel Kiln Sponge Iron Furnace. P. E. Cavanagh. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.62). [In English].

The Iron and Steel Industry of Finland. Sir Charles F. Goodeve. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 219–222). [This issue].

Steel Production in Latin America. G. Bulle. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L. 55). [In English]. The development of steel production in Latin America is discussed. The following problems are considered: (1) Possible steelmaking processes (description, output, comparison) ; (2) layout of steelworks ; (3) requirement of raw and ancillary materials ; (4) special aspects of steelworks planning in the individual countries of Latin America ; and (5) the costs and economics of operation of steel production in Latin America.—V. G.

The Balance of Materials and the Economic Comparison of the Different Steel Making Processes. E. Krebs. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.56). [In English]. The operational economy of the various steel-making processes is compared on the basis of the material balance and conversion costs per ton of crude steel.—V. G.

Description of the Duplex Procedure Used for Manufacturing Steel in Monterrey. A. Gonzales Ballesteros and N. Morales. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.59). [In English]. The operation of the Bessemer/open-hearth duplex process at the Fundidora de Monterrey, Mexico, is outlined.—V. G.

The Acid Bessemer Process in Huachipato (Chile). H. Canguilhem. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.60). [In English]. Main characteristics of the steel melting shop, and in particular the operation of the Bessemer converter, in the only integrated plant in Chile (at Huachipato) are given.—V. G.

Acid Open Hearth Products and Their Specifications. G. R. Fitterer. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.72). [In English]. Advantages of the acid open-hearth process, the quality of steel produced, main application of the acid open-hearth steel, particularly for forging and casting, and specifications for individual types of products are discussed.—V. G.

Thomas Steel with Low Nitrogen and Low Phosphorus Contents. P. Coheur. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.73). [In English]. An account of works trials in the operation of a basic-Bessemer converter in order to obtain low-nitrogen and low-phosphorus steels is given. The following methods were tested : Oxygen-enriched blast ; ore, limestone and soda ash additions ; and blowing steam-oxygen mixtures. The mechanical properties of the steels produced were also tested. It is concluded that by applying oxygen-enriched or a steam-oxygen blast, a steel of similar nitrogen content to that produced in the open-hearth furnace can be obtained.—V. G.

Brief Account of Iron and Steel Producing Processes Used in Brazil. A. Lanari. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.74). [In English]. Characteristics of the raw materials used in the Brazilian iron and steel industry, the metallurgical methods and processes used and possibilities of future developments are described.—V. G.

Control in Steel Production. G. Weston. (*United Nations*

Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.76). [In English]. The principles underlying the control of steel types according to national specifications in highly industrialized countries are outlined with special reference to the factors which operate in Great Britain. The following items are considered : The control of raw material supplies; composition of the bath and after leaving the furnace ; standardization ; standard specifications ; and methods of testing.—V. G.

Acieries de Champagnole. (*Acier Fins et Speciaux*, 1954, **16**, Feb., 85–88). The foundation and development of the Champagnole Steelworks as well as their present field of production is described.—V. G.

The File Industry in the St. Etienne District. (*Acier Fins et Speciaux*, 1954, **16**, Feb., 74–76). An historical survey of the production of files and a short description of the modern manufacturing methods are given.—V. G.

Tests to Improve the Life of Bottoms and Linings of Converters. Calaque. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (12), 1915–1922). The effects of heating the tar at 110° C., of preparing the dolomite by the elimination of lumps of scaffolds or coke, and of controlling the percentage of unfired dolomite, on the properties of dolomite bricks are reported. The bricks are most compact when fine grain dolomite is used in thin bricks pressed three times, but there is little gain in density.—A. G.

The Oxygen Content of Liquid Bessemer, Open-Hearth, and Electric Arc Steels. K. G. Speith and H. vom Ende. (*Stahl u. Eisen*, 1954, **74**, Apr. 22, 509–522). Aluminium-killed bomb samples have been taken from the contents of converters, open-hearth, and electric arc furnaces, and the oxygen concentrations determined by vacuum-fusion. The temperature of the metal was taken at the same time as it was sampled. The oxygen content of basic-Bessemer steel at the end of the blow is in equilibrium with the supernatant slag, irrespective of whether air, oxygen-enriched air, or pure oxygen has been used for refining. When such blown metal is deoxidized and recarburized by the addition of coke breeze, the carbon and oxygen contents are then at equilibrium with carbon monoxide at 1 atm. pressure. The oxygen contents of open-hearth steels during refining are higher than corresponds to carbon–oxygen equilibrium. The oxygen content can be determined from the rate of carbon drop, if this can be accurately assessed. The actual content of oxygen depends on the rate of oxygen feed and the speed of the carbon reaction. The oxygen contents of electric arc steels similarly lie higher than the [C]–[O] isotherm, whether they are refined with oxygen or with ore. Since it is possible to reduce the oxygen feed to zero in the electric furnace and so allow the bath to go off the boil, oxygen contents in equilibrium with the carbon can be obtained.—J. P.

Use of Oxygen in Steelmaking. J. Vazquez Lopez. (*Anal. Mec. Elect.*, 1953, **30**, Jan.–Feb., 3–20; May–June, 126–140; July–Aug., 171–180). [In Spanish]. The author reviews the application of oxygen in the open-hearth, Bessemer and electric furnace processes and in the ladle, mainly in countries outside Spain. The use of oxygen in top blowing in the converter process is discussed. Details of the steels produced are given with useful comparative data relating to cost. Apart from economy in electric power, the advantage of recovering chromium in the remelting of stainless scrap in the arc furnace is explained.

Improvement of Basic Bessemer Steel—Use of Oxygen. Allard. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (10), 1585–1589). The use of oxygen both for pre-refining and during blowing with the object of improving the quality of Bessemer steel is discussed. Its effects on the contents of phosphorus, sulphur, and nitrogen in steel are considered. Although Bessemer and open-hearth steels of the same grade are not identical in quality, the oxygen content of the former is not necessarily to blame. An appendix gives economic data on installing equipment for blowing oxygen.—A. G.

The Future of Steelmaking: Possible Development of Counterflow Continuous Process as Substitute for the Open-Hearth. M. W. Thring. (Sheffield Soc. Engineers and Metallurgists : *Iron Coal Trades Rev.*, 1954, **168**, Apr. 2, 793–800). The author shows that a conventional open-hearth furnace cannot exceed an overall thermal efficiency of about 50% as it does not provide the ideal temperature cycle for the heat requirements of steelmaking. He outlines an improved system based on the counterflow continuous principle which could give efficiencies up to 70% for a 100% cold-metal process. Its metallurgical advantages are also outlined.

Quicker Heat-Up for Rebuilt Open-Hearth Furnaces. (*Blast Furn. Steel Plant*, 1954, **42**, Apr., 431–433). In the method described three thermocouples are placed above the doors and one in the crown of the roof, and a continuous recording of the temperature at these points is made during heating up. The furnace is heated by the normal gas supply and the rate of heating is controlled automatically in a predetermined manner.—B. G. B.

Oil Speeds the Flow of British Steel. P. Williams. (*Ingot*, 1954, Apr., 1–5). The author traces briefly the history of oil and, after stressing the applications of steel in the oil industry, discusses the use of oil as a fuel in steelmaking. Oil firing enables accurate control to be maintained, it promotes a fast rate of melting, and oil-fired furnaces are simpler in construction. A low roof is not needed to direct the flame. The handling and transport of oil are described.—L. E. W.

Modification of the Control of No. 1 Open-Hearth Furnace at the Mont-Saint-Martin Works. Boitel. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (9), 1449–1451). The rate of supply of blast-furnace gas was regulated to a constant value, and the coke-oven gas rate was arranged to return rapidly to its normal value after reversal. In this way significant economies in gas consumption were achieved.—A. G.

Instrumentation Plays Vital Part in Steel Industry Efficiency. W. A. Hannaford. (*B.H.P. Rev.*, 1953, **30**, Sept., 6–8). The author describes how instruments are utilized at the Newcastle Steel Works of Broken Hill Proprietary Ltd. for control of steel production at the temperatures and pressures involved. The planning of the installation and its maintenance are dealt with briefly, and a diagrammatic arrangement of a typical gas flow control meter is included.—L. E. W.

The Basic Open Hearth Process. G. R. Bashforth. (*Brit. Steelmaker*, 1954, **20**, Mar., 88–93; Apr., 134–138). The author reviews the conditions favouring the removal of the various impurities in the basic open-hearth process, and outlines the chemical reactions involved. Sulphur reactions, deoxidation, and Brinell's formula relating blowholes in steel to the manganese, silicon and aluminium in the ingot at the time of casting are dealt with.—R. A. R.

Manganese Recovery in the Basic Open-Hearth Process. N. F. Dufty. (*Blast Furn. Steel Plant*, 1954, **42**, Apr., 428–430). Basic iron produced from Australian iron ores is sufficiently low in phosphorus to permit sand additions to be made to basic open-hearth slags to increase the manganese yield. An examination is made of the lime/silica ratio of the slag for optimum manganese recovery assuming that there is no danger of phosphorus reversion.—B. G. B.

The Present State of Open Hearth Furnace Practice in the East German Republic. K. F. Lüdemann. (*Met. u. Giesserei Techn.*, 1954, **4**, Feb. 85–90). Statistics on the performance of 32 furnaces in Eastern Germany demonstrate that it is up to modern standards. The Maerz design has been particularly successful. The effects on furnace performance of increasing the pig iron to 35% in the cold-pig/scrap process are discussed. The possibility of extending rapid melting techniques is considered.—L. J. L.

Melting-Shop Reconstruction at the Normanby Park Steel Works. John Lysaght's Scunthorpe Works Ltd. J. A. Peacock. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 301–305). [This issue].

The Development of Automatic Control in Open Hearth Furnaces. H. Stollberg. (*Met. u. Giesserei Techn.*, 1954, **4**, Feb., 62–72). National attitudes towards automatic control are postulated : that of the Russians being comparatively negative, that of the United States very much in favour, and Great Britain occupying an intermediate position. The author approves of the British attitude and describes foreign views on the value of automatic control.—L. J. L.

Oxygen Combustion Tests on an Open-Hearth Furnace Fired with Enriched Coke-Oven Gas. G. Husson and J. Donney. (*Rev. Mét.*, 1954, **51**, Apr., 283–290). Trials covering a whole campaign are reported on oxygen injection into the flame of an open-hearth furnace fired with cold enriched gas. As with oil-fired furnaces, a saving in fuel and an increase in output is achieved but refractory wear is considerable. Limiting the period of injection, improved burner design, and the strict

control of roof temperature may make the technique of greater economic advantage.—A. G.

Slag Control in the Basic Open-Hearth Furnace. Bernard. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (12), 1923–1934). The aims of slag control are outlined and the determination of its oxidizing power, the recovery of manganese, and the scientific practice of deoxidation are discussed. Advantages are stressed and the main available methods of slag control are considered. At the Creusot works the appearance of slag buttons of different basicity provides a good indication of chemical composition.—A. G.

Mechanical Fettling of Open-Hearth Furnaces. (*Stahl u. Eisen*, 1954, **74**, May 6, 620–623). The paper contains two brief reports on the use of the Blaw-Knox 'slinger' and the time-saving achieved thereby, one on the design and operation of the Brieden machine, and one on the use of a mobile magnesite or dolomite sprayer for roof and back-wall repairs. The Brieden machine is made in England.—J. P.

The Operation, and Recent Data of Wear, of Open-Hearth Furnaces with Basic Lining. L. Hütter. (*Radex Rundschau*, 1954, (1–2), Jan.-Feb., 36–57). Practical experience and data of open-hearth operation are described and discussed. Great importance is attached to correct adjustment and overhauling of the buffer springs of the suspended roof. Accurate temperature control is stressed as essential. Air cooling of the roof increases heat consumption but prolongs service life considerably. Correct selection of lining material and appropriate heating-up procedure are advocated for best results. Recent performance data for Austrian, British, and Russian linings are compared.—E. C.

Study on Manufacture of the Low Carbon Pipe Steel by Basic Open-Hearth Process. J. Terada. (*Tetsu to Hagane*, 1951, **37**, Dec., 661–666). [In Japanese]. Results are presented of a committee investigation into the quality of steel ingots for solid drawn tubes. Ingots produced by four works were examined.—K. E. J.

Study on the Reduction Equilibrium of Ferrous Sulphide by Carbon Monoxide. T. Uno and E. Honma. (*Tetsu to Hagane*, 1951, **37**, Dec., 627–632). [In Japanese]. The equilibrium constant of the reaction $FeS + CO = Fe + COS$ and its temperature coefficient were determined within the range 800–1100° C. Equilibrium data were deduced for the equations $FeS + CO_2 = FeO + COS$, $3FeS + 4CO_2 = Fe_3O_4 + CO + 3COS$, and $CO + \frac{1}{2}S_2 = COS$.—K. E. J.

On the Ionic Behaviour of Slag in Steelmaking. Y. Matsushita. (*Tetsu to Hagane*, 1951, **37**, Nov., 561–569). [In Japanese]. Experimental results show that ionization of slags increases as temperature rises, and conductivity measurements indicate the existence of several complex anions. A fundamental formula for slag basicity is proposed, this quantity being connected with the Martens hardness of quenched slags. The Grotthus type mechanism of conductance is supported. Results concerning the FeO activity in the $CaO–SiO_2–FeO$ system are interpreted. (28 references).—K. E. J.

Electrolysis of Fused Ferrous Slags. O. A. Esin and P. M. Shurygin. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94**, (6), 1145–1147). [In Russian]. The cathodic precipitation of iron from fused slags was investigated. Liquid gold was used as a cathode and to minimize the influence of the reaction $Fe^{3+} + e \rightarrow Fe^{2+}$ the anode was separated by a diaphragm of powdered magnesite. The following slags were tested : (1) $FeO–Fe_2O_3–SiO_2$; (2) $FeO–Fe_2O_3$; (3) 45% ($FeO + Fe_2O_3$), 20% CaO, and 35% $2SiO_2$; (4) 65% ($FeO + Fe_2O_3$), 15% CaO, and 20% SiO_2 ; (5) 40% ($FeO + Fe_2O_3$), 30% CaO, and 30% SiO_2 ; and (6) 40% ($Fe_2O_3 + FeO$), 20% Al_2O_3, and 40% SiO_2. The percentage of current output is plotted against degree of oxidation of the slag. Experimental results are discussed.—V. G.

The Greaves Etchell Furnace. Babel. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (8), 1273–1282). Details are given of the construction and electrical installation of a furnace with a rectangular conducting hearth. Disadvantages include the short hearth life, particularly in discontinuous operation and the difficulties of repair. The construction is envisaged of a 100-ton Héroult furnace with two 3-phase transformers each serving three electrodes and having a high melting rate.—A. G.

Modern Arc Furnace Equipment and Practices. E. H. Browning. (*Iron Steel Eng.*, 1954, **31**, Mar., 70–74). The author describes trends in the use of electric furnace equipment, discusses comparative equipment costs, the effect of high secondary voltages and furnace ratings. Furnace transformers, circuit breakers, and regulators are also described.

Study on the Melting of Cast Steel by the Basic Electric Arc Furnace (Supplement). T. Kinoshita. (*Tetsu to Hagane*, 1951, **37**, Apr., 208–212). [In Japanese]. The mechanical properties of the cast steel depend on the melting practice, particularly non-metallic inclusions ; these are at a minimum at 0·3–0·4% silicon contents. Elongation is particularly affected by the silicon content, and this should be rectified to 0·3–0·4% when melting conditions are abnormal.—K. E. J.

Effect on the Non-Metallic Inclusions of the Smelting Process in the Basic Arc Furnace. H. Ishizuka. (*Tetsu to Hagane*, 1951, **37**, July, 397–404). [In Japanese]. Refining conditions for making clean high-carbon chromium steel are postulated; the recommendations include oxidizing, killing, control of carbon, silicon and chromium contents, and slag conditions. (17 references).—K. E. J.

Low Carbon Electric Steel: Practice and Installations in the United States. J. C. Howard. (*Iron Steel*, 1954, **27**, Mar., 95–98). The author has studied the use of large arc furnaces in the U.S.A. for the production of the lower grades of steel. He describes some American installations and the practice employed.—G. F.

Flexible Leads for Low Frequency Electric Furnaces. M. Eaton and S. B. Thomas. (*J. Electrochem. Soc.*, 1954, **101**, Feb., 110–116). The requirements of leads to arc furnaces are outlined and the advantages of water-cooled cables are traced.—A. D. H.

Le Tourneau Steel Plant Contains Unusual Features. (*Iron Steel Eng.*, 1954, **31**, Apr., 146–148). A brief description is given of the plant of R. G. Le Tourneau, Inc., Longview, Texas, which includes three 25-ton electric arc furnaces and a 4-high 144-in. reversing plate mill. The furnaces are tilted by a cable hoist working on a jib boom mounted under the furnace. Scrap is loaded into a large scoop mounted on a carriage of special design. The scoop is run into the chute on the furnace and a ram pushes it out of the scoop. The ingot reheating furnace is a refractory lined steel cylinder 80-ft. long and 20 ft. in. dia. with burners along each side, one row tilted upwards and the other downwards ; this gives the gases a whirling motion. The ingots are pushed along skids through this slightly sloping furnace.—R. A. R.

Advantages of Insulating an Acid Electric Furnace Roof. C. C. Spencer. (*Trans. Amer. Found. Soc.*, 1953, **61**, 593–594). The use of a 1 in. thick vermiculite plaster lining on top of the usual silica roof has been a major factor in raising the average roof life from 170 to 400 heats. The insulation reduces spalling of the roof bricks, prevents penetration of iron oxide and dirt from outside, and gives more uniform power consumption.

Japanese Experiments on Air Lancing in the Electric Furnace. K. Kato and T. Tsukimoto. (*Iron Coal Trades Rev.*, 1954, **168**, May 7, 1097). A summary is given of the results of Japanese experiments using a compressed air blast for steel refining in the electric furnace in a total of 72 heats. The results obtained with nitrogen lancing are also summarized; they confirm that the essential function of the lance is mixing rather than oxidation.—G. F.

Design and Manufacture of Ingot Moulds. J. H. Shank. (*Amer. Iron Steel Inst. Regional Technical Meetings*, 1953, 245–253: *Blast Furn. Steel Plant*, 1954, **42**, Jan., 70–72: *Indust. Heating*, 1954, **21**, Feb., 284, 286, 291–296). Details are given of different moulds employed for 5-ton ingots. The design finally adopted has a mould/ingot ratio of 1·02, measures 22 × 23 in. internally, and has slight corrugations. A life of 80 heats is obtained without using coatings. The manufacturing process is described. Manganese contents above 1% are avoided.—R. W. B.

Evolution of Gases from Rimming-Steel Ingots. Y. Shimokawa and T. Tanoue. (*Tetsu to Hagane*, 1951, **37**, Nov., 555–561). [In Japanese]. Studies are reported on the rate of evolution, composition and pressure of gases throughout all stages of solidification of the ingot. The influence of the carbon, oxygen and manganese contents of the metal was determined. The relation between gas evolution and ingot structure was explored, and a mechanism of blowhole formation is put forward.—K. E. J.

Flaw Lines in Steels of High Chromium Content. Soubes. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (11), 1759, 1763–1769). Possible causes, including microporosity and inclusions picked up during refining or casting, and the reactions of chromium with acid slags are discussed. These flaw lines are

markedly reduced by basic melting and refining in a H.F. furnace or by replacing alumino-silicate refractories by magnesia.—A. G.

Aluminium Silicate Inclusions in Steels not Treated with Aluminium in the Ladle. Matheret. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (11), 1745–1757). The topics discussed included: Aluminium silicate inclusions in steels not treated with aluminium in the ladle; gases dissolved in ferro-alloys (including the influence of silicon on hydrogen solubility in liquid iron); the construction of an electric furnace; the duplex electric furnace and open-hearth furnace process, the 18-ton arc furnace of the Fives-Lille company, the axial porosity of ingots, and a new method of casting in moulds of low thermal conductivity with an artificial cooling gradient from top to bottom.—A. G.

On the Method of Rapid Judgement of Basicity of Electric Arc Furnace Slag K. Shinji. (*Tetsu to Hagane*, 1951, **37**, Apr., 203–207) [In Japanese]. Slag basicity may be determined within 5–10 min. by comparison with standard microstructures under a reflecting microscope.—K. E. J.

Metal-Slag Reactions in Steelmaking: Reaction Equilibrium Formulae Used to Calculate Distribution of Manganese, Phosphorus, and Ferrous Oxide. J. Pearson. (*Iron Coal Trades Rev.*, 1954, **168**, Mar. 19, 685–695). Methods for calculating the activities of FeO, MnO, and P_2O_5 from the composition of steelmaking slags are described and typical examples are given. Equilibrium contents of oxygen, manganese, and phosphorus in the steel may be calculated from these activities. The influence of temperature and composition of the metal and slag on the oxygen content of the metal during refining is also discussed.—G. F.

Ingot Mould Made of Cast Steel (II). S. Fukabori and H. Anjow. (*Tetsu to Hagane*, 1951, **37**, June, 337–341). [In Japanese]. The use of mould steel for 600-kg. slabs was reduced from 16 to 15 kg./ton cast. The optimium composition was C 0·40–0·50, Si 0·25–0·35, Mn 0·60–0·80, P <0·03 and S < 0·03%. The use of ribs reduces strain.—K. E. J.

Coatings for Ingot Moulds. Thomas. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (9), 1241–1429). Washes are employed to prolong mould life and reduce surface defects in ingots. They provide physical protection for the mould and can minimize all the principal defects of ingots such as cracks and blowholes. Their more general use is restricted by the difficulty of selecting the exact composition for the wash and the tendency for recarburization of the steel surface. The various types of wash employed are discussed.—A. G.

Sources of Inclusions from Pouring Refractories Investigated. M. P. Fedock. (Amer. Inst. Min. Met. Eng. Elec. Furn. Steel Conf. : *J. Met.*, 1954, **6**, Feb. Section 1, 125–127). An investigation of inclusion sources has been made on steels made by a double pouring arrangement on 18-ton heats, the extent and pattern of ladle erosion and the slags formed being studied using a tracer technique. The results indicate a critical area within a 18–22 in. radius of the ladle nozzle from which spalled, fused, and eroded material is carried along by the pouring stream.—G. F.

The Temperature Distribution of Ingot Moulds and the Effect of Nozzle Shape of Runner Brick on It. M. Yamaki and S. Suseki. (*Tetsu to Hagane*, 1951, **37**, June, 329–336). [In Japanese]. The occurrence of longitudinal cracks in moulds can be corrected by uniform temperature distribution; one important factor is to use flat shaped runners instead of round ones.—K. E. J.

On the Rate of Solidification, Variation of Molten Metal Composition and Scum During Solidification of Rimming Steel Ingots. Y. Shimokawa and T. Tanoue. (*Tetsu to Hagane*, 1951, **37**, Oct., 503–511). [In Japanese]. A formula is given for the rate of solidification. The sulphur, phosphorus, carbon, and manganese contents of the molten metal increase, and the oxygen content decreases, during solidfication. Scum analyses are given ; these approach those of acid slag.—K. E. J.

The Status of Continuous Casting at Allegheny Ludlum. W. B. Pierce. (*Amer. Iron Steel Inst. Regional Techn. Meetings*, 1953, 45–61). The author discusses the pilot Rossi-Junghans continuous casting machine at the Allegheny Ludlum Steel Corp., Pittsburgh, and describes his experience with it. In addition to providing data for the design of a production machine, the pilot plant serves to develop casting data for a range of sizes and grades of steel and to throw light on economic factors involved. The design of the plant and the operating technique are discussed.—G. F.

The Problem of Rupture of the Billet in the Continuous Casting of Steel. J. Savage and W. H. Pritchard. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 269–277). [This issue].

Segregation of Non-Nickel Steel Ingots. M. Shiozawa. (*Tetsu to Hagane*, 1951, **37**, July, 405–412). [In Japanese]. The degree of segregation in Cr–Mo and Cr–Mn steel ingots is some four times, and of Si–Cr–Mn steel ingots some three times, as great as in carbon or Ni–Cr steel ingots. (18 references).—K. E. J.

Effect of Chromium on the Non-Metallic Inclusion in Molten Steel. (II). H. Ishizuka. (*Tetsu to Hagane*, 1951, **37**, Mar., 158–163). [In Japanese]. The effect of ferrochromium additions on the inclusions was found to vary with slag basicity for acid and basic open-hearth practice. In the basic arc and open-hearth furnaces, inclusions decreased when the CaO/SiO_2 ratio was in the range 2·0–4·5, the maximum effect being at ratios of 2·6–3·0.—K. E. J.

FOUNDRY PRACTICE

The Foundry Industry in the United States of America. R. Weidner. (*Giesserei*, 1954, **41**, Apr. 15, 178–186; Apr. 29, 225–232; May 13, 261–266). Numerous aspects of the foundry industry in the U.S.A. are reviewed. After presenting some statistics, the moulding and melting shops, including the numerous moulding machines, are described. Roller and endless belt systems are compared and many operations in the moulding shop illustrated. A description of core-making departments leads up to methods of sand beneficiation. Pattern making and the cleanings of castings are dealt with and followed by a description of working conditions. Both hand operated and automatic plant are described; operations are depicted in 59 photographs.—R. J. W.

Combustion of Fuel in a Cupola. A. K. Fanbulov. (*Liteĭnoe Proizvodstvo*, 1954, (2), 21–24). [In Russian]. The combustion of fuel in cupolas is considered with respect to the properties of the fuel, temperature of the blast, oxygen-content of the blast, and composition of the top gas. The combustion of mineral coke, charcoal, and peat is compared and the thermal advantages of using peat are pointed out. Combustion-zone effects in the blast-furnace are compared with those in cupolas. The influence of the sizing and reactivity of a fuel on the combustion efficiency in cupolas is discussed with references to the literature.—S. K.

Use of Oxygen in Melting Low-Carbon and Superheated Cast Iron. V. A. Fuklev. (*Liteĭnoe Proizvodstvo*, 1954 (2), 1–3). [In Russian]. Experiments on the treatment of cast iron with oxygen in the fore-hearth of a cupola to give a metal suitable for the production of high-quality malleable iron are described. The observed extents of oxidation of various elements are contrasted with data in the literature and examined thermodynamically. The mechanism of oxidation in cast iron is considered. The iron was deoxidized by adding 0·02–0·03% of aluminium in the ladle, which also increased the number of graphitization nuclei and improved the mechanical properties.—S. K.

Use of Cupola Thermoanthracite for Melting Cast Iron. E. E. Erenburg. (*Liteĭnoe Proizvodstvo*, 1954, (2), 24–26). [In Russian]. In the experiments described, various fuels for the cupola were compared using the following procedure: The fuel under test was stacked to a height of 1800 mm. in a previously heated cupola 400 mm. in dia. After 10–20 min. the height of the bed was levelled off and the blast admitted. Durations of the descent of the column to the tuyere level and the hearth level were determined for four types of coke, three types of anthracite, peat, and charcoal. From the results it is concluded that cupola ' thermoanthracite ' (produced by a fairly rapid heat-treatment of anthracite) is an excellent cupola fuel.—S. K.

Melting, Desulphurizing and Refining Cast Iron in the Cupola. F. Rodrigez-Yufera y Munoz. (*Anal. Mec. Elect.*, 1953, **30**, Mar.-Apr., 68–78; May-June, 141–151; Sept.-Oct., 253–261). [In Spanish]. The author gives details of the melting process, desulphurizing, and refining of cast iron in the cupola, noting the influence of the various factors such as size, quantity and quality of coke, volume and temperature of air blast, type, dimensions and lining of the cupola, and fluxes. The use of manganese as a desulphurizing agent is discussed. Various desulphurizing processes, including that of Kalling, are described. The use of oxygen in the basic-lined cupola is surveyed.—R. S.

Desulphurizing Cupola Cast Iron with Serpentine. O. P. Mchedlov-Petrosyan and P. P. Petrosyan. (*Liteĭnoe Proizvodstvo*, 1954, (2), 26). [In Russian]. Results of tests lasting 2 min. using raw or calcined serpentine for desulphurizing cast iron are presented. For some tests the finely powdered mineral was added directly to the metal in the ladle. With raw serpentine and an iron containing 0·143% S a maximum desulphurization of 35·5% was obtained, the corresponding figures for calcined serpentine being 0·104 and 61·1%. In another test the mineral was used to coat the ladle-lining and here an iron with 0·117% S was desulphurized by 47·0%. The advantages of the serpentine over the soda-ash process are briefly mentioned.—S. K.

The Design, Installation, and Operation of a Water-Cooled Cupola. (*Usine Nouvelle*, 1954, **9**, Feb. 4, 53–55). A cupola with a 3 ft. 2 in. hearth, making ordinary grey phosphorus iron, has been cooled by iron segments containing steel tubes. The cooling system is robust and does not increase coke consumption or lower iron temperature. The advantages obtained are a reduction in the quantity of fettling material required, a saving in repair times, and a closer control of slag composition in the absence of refractory pick-up from the lining.—A. G.

Works Experience with the "Esslinger" Hot-Blast Cupola. H. Kopp. (*Giesserei*, 1954, **41**, Apr. 15, 186–193). The development of the hot-blast cupola is traced and different types are described. The effect of blast temperature and the amount of air supplied is considered and related to the combustion ratios within the furnace, *e.g.*, the CO/CO_2 ratio. Observations of the metallurgical processes which take place both before and during the melting are presented and discussed. Data on the melting efficiency and the economics of running the furnace are reported.—R. J. W.

Foundry Prepares Own Refractory for Lining and Patching Cupolas. H. F. Scobie. (*Amer. Foundryman*, 1954, **25**, Feb., 46–48). The cupola melting practice at the Golden Foundry Co., Columbus, Indiana, is briefly described and details are given of the plastic refractory (a mixture of mica schist and fireclay) which is used for ramming and patching the lining.

Gun Placed Silica Cupola Lining. T. E. Barlow and P. D. Humont. (*Trans. Amer. Found. Soc.*, 1953, **61**, 378–386). The techniques of handling both the cupola and the cupola patching equipment in order to obtain maximum benefit from monolithic patches are discussed in detail. Particular attention is paid to the correct method of building up and contouring the patches. The factors affecting refractory wear in general in a cupola are also considered.—B. C. W

Duplexing in the Foundry. F. J. Knight. (*Metallurgia*, 1954, **49**, Mar., 137–138). A method of using a cupola and an arc furnace together in a foundry is described. The iron is melted in the cupola from which it is tapped at 1505° C. The metal is then led through a trough with a built-in desulphurizing fore-hearth to the electric furnace where the temperature is raised to 1565° C. After 20 months operation the savings in remelted iron, reduced scrap, and reduced coke consumption had more than offset the cost of the electric furnace.—B. G. B.

Phosphorus Removal in Basic Cupola Operation. J. E. Bolt and W. C. Jeffery. (*Trans. Amer. Found. Soc.*, 1953, **61**, 546–551). Results are presented of a study of the removal of phosphorus in an experimental basic-lined cupola. It is concluded that dephosphorization is increased by oxidation, low silicon in the metal, low metal temperature, and increased limestone in the charge. If a basic cupola is operated under conditions which remove phosphorus, the low metal temperatures necessitate either duplexing the iron or casting it directly and remelting.—B. C. W.

Acid Cupola Slags and Some Relationships with Melting Conditions. S. Carter and R. Carlson. (*Trans. Amer. Found. Soc.*, 1953, **61**, 527–539). An attempt is made to correlate the analyses of 130 slags from six different cupolas with the melting practice employed. The fluidity of the slag decreased almost linearly with increasing silica content, and the slag composition was found to vary with the cupola size, type of lining, lining practice, type of coke, size of coke, amount of coke, method of charging, volume of air, size of steel scrap, and the use of hot blast. The effect of these and other variables on slag control is considered.—B. C. W.

Casting Motorcycle Cylinders. L. Matuščík. (*Slévárenství*, 1954, **2**, (4), 108–113). [In Czech]. It is shown that inoculated cast irons made in the cupola with a fore-hearth or in a high-frequency furnace are best for the above castings. The composition and physical properties of suitable types of cast irons are given. Moulding without boxes in synthetic sand mixtures bonded with propane-asphalt and starch binders was found very satisfactory.—P. F.

The Mode of Operation and Operating Data of an 800-kg. Low-Frequency Induction Crucible Melting Furnace. H. Rohn. (*Giesserei*, 1954, **41**, Mar. 18, 134–137). The theoretical basis of low-frequency heating is first considered briefly. The construction and operation of a 50-cycle melting furnace with an 800-kg. lining is described. Economic melting programmes for three different charging schedules are outlined.—R. J. W.

Efficient Methods of Production of Machine Tool Castings. G. W. Nicholls. (*Trans. Amer. Found. Soc.*, 1953, **61**, 29–51). A comprehensive account is presented of the manufacturing methods and control systems used in the production of machine tool castings by Modern Foundries Ltd., Halifax. Details are given of all phases of the work from pattern design to melting practice. The author stresses that a continuous study of foundry processes results in lowering the cost of castings and in better quality, with a reduction of waste in materials and in machine-shop hours.—B. C. W.

Sulphur in Cast Iron Treated with Magnesium. V. R. Balinskiĭ. (*Liteĭnoe Proizvodstvo*, 1954, (2), 18–19). [In Russian]. Investigations on the effects on sulphur in cast iron of inoculation with magnesium are described. The iron (3·2–3·5% C, 1·9–2·4% Si, 0·5–0·7% Mn, 0·2–0·3% Cr, 0·2–0·3% Ni, 0·10–0·12% P, 0·05–0·13% S) was treated with a 1 : 1 : 1 mixture of magnesium, cast iron and 75% ferrosilicon. Distributions of sulphur, manganese, and magnesium in castings and, less thoroughly, in the liquid iron, were determined, and microstructures of castings were studied. Similar experiments were made with remelted iron and the effects of remelting on sulphur and magnesium contents were dealt with. The determination of sulphur in magnesium-inoculated iron is discussed together with the effect of magnesium sulphide on the formation of cavities in castings.—S. K.

Evaluation of Casting Processes. P. W. Beamer and S. C. Tingquist. (*Product Eng.*, 1954, **25**, Mar., 139–144). The six basic casting methods of sand, resin-bonded shell, plaster, investment, permanent mould, and die casting are compared on a basis of certain criteria. These include, size and weight, physical properties, dimensional tolerances, configuration and cost, and they must be considered in reaching a decision on which type of casting to employ.—A. M. F.

Progress in Shell Moulding. (*Metal Treatment and Drop Forg.*, 1954, **21**, Feb., 57–60). A review is given of the essential technique of the shell-moulding process, in which moulds for the production of metal castings are made by applying a mixture of sand and phenolic resin to a heated pattern. The heat softens the resin and the pattern acquires a dough-like coating about a $\frac{1}{4}$ in. thick. Excess sand and resin are thrown off, and the coating is turned into a strong shell by further baking. New equipment for this process, by Fairbairn Lawson Combe Barbour Ltd., Leeds, is described and its operation illustrated.—P. M. C.

Shelmolda Shell Mould Making Equipment of Simple Construction. (*Machinery*, 1954, **84**, Feb. 26, 431–436). Shell mould making equipment developed by Fairbairn Lawson Combe Barbour, Ltd., Leeds, and marketed under the trade name 'Shelmoda' is described. The plant, which is simple in construction, includes dump box, roller track with an invested pattern plate, oven, and pedal-operated stripping devices.—M. A. K.

Casting Stainless Steel and Other Alloys in Shell Moulds. (*Machinery*, 1954, **84**, Apr. 23, 853–860). Methods employed by Langley Alloys Ltd. in the shell moulding process for nickel alloys, stainless steels, and aluminium bronze are described. Equipment developed by the firm has a production rate of 90 complete moulds per hour. Details of patterns, dump box, methods of curing and stripping, and core making are given.—M. A. K.

One Company's Experience with Shell Mould Casting. T. W. Curry. (*Mat. Methods*, 1954, **39**, Feb., 102–104). The experiences of the American Lynchburg Foundry Co. in shell mould casting practice are reviewed. Dimensional tolerances, quality of finish, reduction of machining, and cleaning operations are discussed.—P. M. C.

Shell Moulding: New Machine Developed. C. Potter. (*Iron Steel*, 1954, **27**, Feb., 70–72). A description is given of the 'Shelmolda' machine developed by Fairbairn Lawson

Combe Barbour Ltd., mainly as a means of handling the pattern plate easily and efficiently in the curing process in shell-moulding. Production time and costs are considered, and mention is made of some of the snags which may be encountered in shell-moulding.—G. F.

Clamping Shell Moulds. D. Brooks. (*Canad. Metals*, 1954, **17**, Jan., 24). A new method of clamping shell moulds together by placing the two halves in a pneumatically operated clamp before casting, is described.—B. G. B.

New Shell Moulding Techniques. (*Machinery*, 1954, **84**, Apr. 16, 803–805). Two recently published patents granted to the Ford Motor Co. are concerned with methods of casting hardened metal parts by the shell moulding process. A method of chill hardening certain parts of a camshaft by means of compressed air impinging on the mould surfaces, and the design of a gate plate for use in the manufacture of exhaust valves of steel high in chromium and nickel are described.

Quantity Production of Engineering Castings. J. Burrell. (*Found. Trade J.*, 1954, **96**, Feb. 11, 149–155; Feb. 18, 183–190). The reorganized foundry of Marshall Sons and Co. Ltd. is described with particular emphasis on the equipment and process control of the batch production unit which produces large numbers of tractor castings. The production methods applied to several medium-heavy castings are described and illustrated.—B. C. W.

In the Steel Foundry–17. The Daimler Co. Ltd., Coventry. (*B.S.F.A. Log*, 1953, (21), Dec., 5–9). A description is given of the Daimler Co. Ltd. Foundry at Coventry. The equipment and techniques employed in patternmaking, coremaking and moulding, steelmaking, fettling, and heat-treatment are covered briefly. Labour relations and amenities are discussed.—L. E. W.

In the Steel Foundry—18. William Beardmore & Co. Ltd., Glasgow. (*B.S.F.A. Log*, 1954, (22), Apr., 6–10). A description is given of the William Beardmore & Co. Ltd. (Glasgow) steel foundry at Parkhead with details of the equipment and techniques employed in moulding, steelmaking, dressing, heat-treatment and machining.—L. E. W.

New Mechanized Foundry Incorporates Modern Features. (*Commonwealth Eng.*, 1953, **41**, Dec. 1, 173–177). A description is given of the new mechanized foundry of Stewarts and Lloyds (Australia) Pty. Ltd. at Kilburn, South Australia, designed for the production of malleable cast-iron pipe fittings.

Rejects in the Foundry. J. Pascal. (*Mét. Constr. Mécan.*, 1954, **86**, Jan., 25–29; Feb., 109–110). The economics of foundry operation are considered in detail. The difficulties involved in the manufacture of a number of objects are explained to illustrate how the casting methods can be unsuitable for their production. Care should be taken in using moulding sand which has been employed previously for a different type of work. Attention should be paid to the initial design of the pattern to avoid very thin sections. Daily examination of castings produced by mechanized methods should be made after removal of the sand.—B. G. B.

Casting Defects . . . Their Causes and Remedies. W. M. Halliday. (*Foundry*, 1954, **82**, Feb., 113, 183–184, 186, 188). The common casting defects, *i.e.*, porosity, blowholes, cracks, scabbing, loose sand spots, laps and shrinkage, are discussed together with methods of avoiding their occurrence. The repair of faulty castings is briefly considered.—B. C. W.

Estimation and Influence of the Gaseous Elements in Cast Iron. L. W. L. Smith, B. B. Bach, and J. V. Dawson. (Inst. Brit. Foundrymen: *Found. Trade J.*, 1954, **96**, Mar. 4, 233–238; Mar. 11, 275–280; Mar. 18, 303–309). The vacuum-fusion method for determining the gas content of cast iron and the problem of sampling for such analysis is briefly outlined. The effects commonly attributed to oxygen, hydrogen, and nitrogen in cast iron, and the published work on the effects of these elements are reviewed. Results of experiments carried out at the B.C.I.R.A. on nitrogen in cast iron are reported in detail. Nitrogen was found to stabilize the carbide both during solidification and in any subsequent heat-treatment. Nitride forming elements like boron, titanium, and particularly aluminium, neutralize the carbide stabilizing effect of nitrogen. It is pointed out that the effects of nitrogen and oxygen are difficult to separate as most of the deoxidizers are also nitride formers.—B. C. W.

Approach to Foundry Mechanical Handling. C. M. G. Wallwork. (*Found. Trade J.*, 1954, **96**, Feb. 25, 203–209; Mar. 4, 241–246). The author outlines the methods which he has used in deciding how to mechanize in a foundry. Reasonably accurate costing is necessary to assess the comparative value of different schemes, and work study methods must be used in determining the places where mechanical handling will produce the best results.—B. C. W.

Planning the Lighting Equipment in Foundries. A. Metzeler. (*Giesserei*, 1954, **41**, Feb. 4, 62–66). The method of analysing the whole situation is first given. The way to plan a scheme for the lighting equipment is then given and followed by a description of the economics of different types of lighting. Many examples are given of the cost of lighting by the different methods. A calculation is given of the requirements for suitable local and mean intensity of illumination. The requirements for lighting a foundry are detailed.

Iron and Steel Foundries Regulations 1953: Their Relationship to Safety. Sir George Barnett. (*Found. Trade J.*, 1954, **96**, Mar. 11, 265–269). The author discusses the particular Regulations that have been drafted to provide better working conditions and improved standards of safety in foundries. They deal with the arrangement and handling of plant and materials, the handling and transport of molten metal, the prevention of fumes and dust, particularly from open fires and knock-out stations, and the provision and use of protective clothing. It is pointed out that little or no progress appears to have been made in the past 4–5 years in reducing the total number of accidents in foundries and that while accidents in industry as a whole are decreasing, those in foundries are increasing.—B. C. W.

Work Simplification Saves $300,000 in Six Years. W. S. Williams. (*Amer. Foundryman*, 1954, **25**, Feb., 54–57). Work simplification is defined as the organized application of common sense to eliminate all waste of time, effort, material, equipment, and space. The ways in which it has been applied at the Lynchburg Foundry Co., Lynchburg, Va., are discussed and examples of the savings which have resulted are given. The author stresses the importance of the human element in foundry work.—B. C. W.

Health Protection in Foundry Practice. (*Amer. Foundrymen's Soc.*, 1952). This 170-page book presents the papers read at a conference at the University of Michigan School of Public Health on Apr. 11–12, 1952, in collaboration with the Michigan Department of Health, Detroit City Department of Health, Institute of Industrial Health, Department of Production Engineering, and the American Foundrymen's Society. The papers of interest to iron and steel foundries were:

Nature of Disease Caused by Dust. O. A. Sander. (7–10).
Measurement of Dust in Foundries. D. E. Van Farowe. (11–24).
Housekeeping. H. J. Weber. (25–34).
Isolation, Substitution and Wetting Agents. E. Meiter. (35–40).
Respirators. A. J. Kaimala. (41–47).
Ventilation Principles. W. N. Witheridge. (48–57).
Sand Handling. R. H. Moore. (58–67).
Coremaking and Molding. G. E. Tubich. (68–76).
Metal Melting and Pouring. J. C. Radcliffe. (77–82).
Shake-Out and Core Knockout. J. M. Kane. (83–96).
Casting Cleaning. W. W. Dodge. (97–118).
Casting Grinding. K. E. Robinson. (119–125).

Trends in Dust Control—Past, Present and Future. K. J. Caplan. (*Trans. Amer. Found. Soc.*, 1953, **61**, 394–398). Some of the general aspects of dust control in foundries are discussed.—B. C. W.

Air Pollution and Public Relations. J. M. Kane. (*Trans. Amer. Found. Soc.*, 1953, **61**, 662–663). It is stressed that more publicity should be given to the efforts being made by the foundry industry in the control of dust and fumes.

Trends in Cupola Dust Collecting Systems. K. M. Smith. (*Trans. Amer. Found. Soc.*, 1953, **61**, 731–732). Medium and high efficiency cupola dust collecting systems are very briefly reviewed.—B. C. W.

Air Pollution Control Equipment for Melting Operations in the Foundry Industry. R. T. Pring. (*Trans. Amer. Found. Soc.*, 1953, **61**, 467–478). The equipment available for the elimination of atmospheric pollution arising from cupolas, reverberatory furnaces, and electric furnaces is discussed in the light of the most stringent anti-pollution regulations so far introduced in the United States. Among the equipment considered are cloth bag filters, Cottrell precipitators, sonic agglomerators, vortex collectors, stack washers, and venturi scrubbers.—B. C. W.

Foundry Noise and Its Control. H. T. Walworth. (*Trans. Amer. Found. Soc.*, 1953, **61**, 694–700). The general problem of industrial noise is discussed and results presented to show the noise spectra corresponding to various foundry operations. Methods of reducing the level of noise and ways of protecting personnel from undue exposure to noise are then considered.

HEATING FURNACES AND SOAKING PITS

An Investigation of Reheating Furnace Design and Performance. F. A. Gray and S. H. Brooks. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 223–266). [This issue].

The Operation of Soaking Pits. J. Dodd. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 297–300). [This issue].

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Design, Manufacture and Behaviour of Flame-Hardened Gears. H. W. Grönegress. (*Rev. Mét.*, 1954 **51**, Mar., 165–172). Flame-hardening may be rotatory or 'tooth by tooth.' Its effect on the resistance to wear, fracture, and fatigue is discussed and formulæ are given for the design of flame-hardened gears. The techniques involved are described and possible economies in steel, labour, and power are considered.—A. G.

R.F. Heating Simplifies Hardening. O. W. Noeske. (*Steel*, 1954, **134**, Mar. 15, 120–121). The employment of a 50-kW. radio-frequency induction heating unit for hardening a variety of steel tool parts is reported. A moving carriage allows shafts up to 41 in. long to be progressively hardened.—D. L. C. P.

Shallow Case-Hardening by a High-Intensity Induction Technique. (*Machinery*, 1954, **84**, Mar. 26, 650–652). Equipment recently developed by the Heat-Treatment Division of the Electric Furnace Co., Ltd. for the surface hardening by high-frequency induction of work pieces in cast-iron and carbon and alloy steels is described. High power densities per unit area are obtained, with the result that heat patterns can be closely controlled.—M. A. K.

Measurement of Case Depth after Carburization. J. Taylor. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 291–296). [This issue].

Induction Surface Hardening of Steel Castings. G. W. Seulen. (*Giesserei*, 1954, **41**, Jan. 21, 40–41). The author describes the surface hardening process for cast steel by induction heating and subsequent quenching in oil, water or air. By using medium frequency heating, a hard surface layer may be obtained to a depth of 1–8 mm. Examples are given of the physical treatment for different types of steel. The advantages of the method are outlined.—R. J. W.

Nitriding of Tool Steel. A. N. Serov. (*Stanki i Instrument*, 1953, (9), 18–20). [In Russian]. The investigation described was carried out to explore the possibility of improving the cutting properties of three widely used tool steels by nitriding before heat-treatment. Nitriding times of 4·5, 12, 26, and 55 hr. were used for each steel, the depth of the ϵ-phase layer and the over-all depth of the nitrided layer being determined. Changes in hardness at various depths in the specimens after nitriding, hardening, and tempering were found. Special specimens were used to find resistance to wear, which was found to be greatly increased by the treatments used.—S. K.

Nitriding of Iron. I. R. Krichevskii and N. E. Khazanova. (*Doklady Akademii Nauk S.S.S.R.*, 1950, **71**, (3), 481–484). The influence of temperature and ammonia concentration on the kinetics of formation of the γ^1 phase was investigated. The reactions involved and the mechanism of formation of the nitrided phase are discussed.—V. G.

Thermal Treatment of Weldments. A. Luthy. (*Welding Metal Fab.*, 1954, **22**, Mar., 108–111). The examples of stress relieving described include the use of an electrically heated pit furnace the height of which can be increasing by placing an additional heating ring above the floor level. Several examples of stress-relieving part by a large structure of medium-frequency induction are also described and illustrated.

Portable Base Brightens Annealers' Future. (*Steel*, 1954, **134**, Mar. 8, 127–128). Advantages of single-stack, portable base, radiant convector furnaces (compared with multiple-stack furnaces) for quality annealing of strip coils are pointed out. These include : Improved product quality ; more even heats in minimum time ; fuel economy ; lighter structures ; and convenient maintenance.—D. L. C. P.

Stress Relieving Furnace at Minimum Investment. F. M. Burt. (*Indust. Heating*, 1954, **21**, Feb., 264–268). Brief particulars are given of a lightweight furnace built from an old unit. Four-zone temperature control is employed.

Roller-Hearth Furnace for Bright Annealing of Strip Steel in Coils. W. Trinks. (*Indust. Heating*, 1954, **21**, Jan., 80–81). This is an abridged English version of a paper by J. Keutmann and H. M. Junius in *Stahl. u. Eisen*, 1953, **73**, Jan. 29, 147–158 *see J. Iron Steel Inst.*, 1953, **174**, June, 176.

How to Determine Quenching-Distortion Properties. J. E. Campbell and H. O. McIntire. (*Iron Age*,, 1953, **172**, Dec. 17, 140–143). A test developed by the Battelle Memorial Institute can be used to determine what steels and heat-treatments should be used to keep distortion to a minimum. Flat specimens were quenched only on one side and the temperature on either side together with the distortion at the centre were measured. Results for a number of steels are given and it is shown that minimum distortion is obtained on steels with just enough hardenability to harden through.

Salt Bath Quenching. (*Automobile Eng.*, 1954, **44**, Feb., 83–85). Data are presented on current American isothermal treatment practices. The principles of cyclic annealing, austempering, and martempering are outlined, and the design and structural features of salt baths are discussed. Information is given about typical applications of these processes in various large American automobile plants.—P. M. C.

FORGING, STAMPING, DRAWING, AND PRESSING

Continuous Crankshaft Press Forging. (*Mech. World*, 1954, **134**, Mar., 110–111). The crankshaft producing plant of the American Chrysler Corp. is described. A flow sheet is given illustrating the full sequence of operations from the billet to finished crankshaft stages. The plant includes an annular furnace with automatic electro-mechanical handling devices in which the billets are heated for forging.—D. H.

Rubber Pad Press Gets New Muscles. (*Steel*, 1954, **134**, Mar. 22, 98–100). The Verson-Wheelon press, a modification of the rubber pad press, can apply a uniform and high pressure to all parts of work being formed ; the principle, practice, and applications are described.—D. L. C. P.

Adjustable Speed D.C. Drives for Deep-Draw Presses. C. E. Robinson and A. P. DiVincenzo. (*Trans. Amer. Inst. Elec. Eng.*, 1953, **72**, Part II, 9–16). Fundamental drive considerations concerning D.C. adjustable speed drives for deep drawing presses are discussed and a typical drive is described.

New Radial Forming Technique for Fabricating Sheet Metal Parts. (*Machinery*, 1954, **84**, Mar. 12, 551–553). A new stretch forming technique for fabricating aluminium and stainless steel sheet, has recently been developed by the 'Ryan Aeronautical Co. (U.S.A.). The process employs massive expanding tools capable of exerting radial forces up to 4800 tons, and it is claimed that large circular shapes can be formed to close limits of accuracy.—M. A. K.

Examples of Efficient Methods of Producing Motor-Car Accessories. (*Machinery*, 1954, **84**, Apr. 16, 783–789). Typical arrangements employing transfer presses, progressive dies, and thread-rolling operations at A.C. Spark Plug Division of General Motors, U.S.A. are described.—M. A. K.

Roll Flowing Saves Operations and Conserves Material. C. L. Sporck. (*Machinist*, 1954, **98**, May 8, 782–785). An entirely new concept in plastic deformation, the Floturn process, developed by The Lodge and Shipley Co., (U.S.A.) is described. In roll forming the flat blank is exactly the same diameter as the finished product and the metal is worked against a hardened mandrel by the radiused periphery of a roll or rollers traversing at a constant rate, so that the metal is gradually formed. No metal is removed but up to 75% thinning occurs. Cones of various shape, with or without steps and corrugations, can be produced.—M. A. K.

Deep Draws Don't Follow Rules. J. W. Gulliksen. (*Steel*, 1954, **134**, Mar. 1, 140–141). It is pointed out that to plan deep-drawing operations may require experience and intuitive understanding of metal behaviour. Examples of the stages in producing several articles are given.—D. L. C. P.

Coatings in Cold Forming—Dual Rôle Makes Lubricant Doubly Important. S. Spring. (*Steel*, 1954, **134**, Mar. 8, 116–119). A review is made of lubricants for use in cold forming operations, and the action and performance of several types are described. Phosphate combinations work

well in the twin function of surface separator and friction reducing agent.—D. L. C. P.

Influence of Phosphorus Content on the Cold Drawing Properties of Mild Steel Sheet. B. Otta. (*Hutnické Listy*, 1954, **9**, (3), 144–147). [In Czech]. A statistical analysis of the effect of phosphorus, heat-treatment, segregation, and combined phosphorus and carbon content on the deep-drawing quality was made on the basis of results obtained in works experiments. Deep-drawing steel, containing about 0·080% P and 0·17% C + P in a casting-pit sample attains the required Erichsen value, but only about two-thirds of this high-phosphorus sheet can be drawn with reductions of 66·7%. Owing to segregation, the phosphorus content in the upper part of ingots may be as much as 87% higher than in the sample, which accounts for the observed reduced yield in deep-drawing.—P. F.

Calculations of Forces and Power Demand for the Ehrhardt Process for Tube-Making. A. Geleji. (*Acta Techn.*, 1953, **7**, (3–4), 477–505). [In German]. This paper gives a mathematical treatment of the mechanical principles involved in the Ehrhardt tube-making process in which a square ingot with rounded edges is fitted, while at 1150–1250° C., into a heavy square die and a mandrel is pressed into the centre. The hollow tube blank is then transferred to a long, slightly tapered, steel mandrel. The blank is reduced to the desired wall thickness by either (*a*) passing through a series of 20 to 25 dies of decreasing diameter, or (*b*) passing through successive sets of shaped rollers, each set consisting of three rollers with their axes forming an equilateral triangle.—R. A. R.

Manufacture of Bright Drawn Bars and Conduits. R. Hammond. (*Mech. Handling*, 1954, **41**, Apr., 180–186). The author describes the manufacture of bright drawn bar and electrical steel conduit tube at the works of Longmore Bros. Ltd., Darlaston. Special mention is made of the pickling and drawing processes with particular reference to the handling problems involved. The monorail and overhead crane systems are discussed.—D. H.

Bright Steel Bar Production. R. B. Russell, W. G. Reid, and A. Fisher. (*West Scotland Iron Steel Inst., Advance Copy* No. 467, Apr. 9, 1954). The three processes for the production of bright steel bars—drawing, turning, and grinding—are described, and the output in the United Kingdom is mentioned. Problems arising in the hot rolling mill are then discussed and the metallurgical investigation of defects is considered ; the most common causes of defects are noted.

Reverse Drawing Gives You Greater Reduction. S. R. Cope. (*Machinist*, 1954, **98**, Apr. 17, 658–660). Reverse drawing means turning a shell inside out to reduce its diameter. By this operation it is possible to reduce the shell diameter by 25% more than is possible by ordinary redrawing dies. Other advantages are that the metal in the walls is subject to less strain, and it is almost impossible to form wrinkles.—M. A. K.

Testing of Materials for Press Work. J. Delgado Diarte. (*Tecn. Indust.*, 1953, **31**, Nov., 1283, 1284, 1336). [In Spanish]. A simple tensile testing machine is described, working with lever and counter-weight, for use with sheet or strip <25 mm. wide and 1–2 mm. thick, and load up to 130 kg./sq. mm. It can be adapted to measure shear or make a cupping test. Drawings are shown.—C. B. L.

Hot Steel Extrusions. T. B. Merill, jun. (*Mat. Methods*, 1954, **39**, Feb., 96, 97). Brief details are given of striking economies realised in the production of two parts in low-alloy Ni–Cr–Mo steels for the Lockheed Constellation Aircraft. Hot extrusion of alloy steel is recommended for shapes too complex to roll, for alloys too brittle to roll, and for small lots of special shapes.—P. M. C.

Self Contained Pump Units As Applied to Extrusion Presses. A. J. de Matteo. (*Steel Processing*, 1954, **40**, Jan., 15–20, 50). The latest developments in self-contained extrusion presses, in which modern variable volume reversible pumps are an integral part of the press structure, are described. The hydraulic circuits of a 900-ton aluminium press employing one 108 gal./min. for the 3000 lb./sq. in. pump, and a 1900–2300 ton piercing type brass extruder employing eight similar pumps, are described in detail and illustrated schematically.

The Glass Extrusion Process for the Hot Extrusion of Steel. J. Sejournet. (*Joint Meeting Iron Steel Inst. and Soc. Ingenieurs Civils de France*, Apr. 1, 1954). The historical development of the Ugine-Sejournet process is outlined, and some of its many advantages in the production of profiled bars and tubes—such as ease and speed of tool changing, comparatively low cost of the plant, low metal losses, and its use for short runs at short notice—are discussed. The mechanism of glass lubrication, which is an essential feature of the process, is outlined, and some observations on the pressures required during extrusion (mild steel at 1150° C. 19,800 lb./sq. in. ; 18/8 stainless 27,800 lb./sq. in. ; 18/4/1 high-speed steel 2,800 lb./sq. in.) are made. It is also emphasized that good lubrication promotes homogeneous deformation and hence uniform properties from end to end of the extruded product. Methods of billet heating are discussed, it being essential to avoid scale formation. Salt-bath heating, low-frequency induction, and controlled atmosphere furnaces are all in use in various plants at the present time.

Notes on the Ugine–Sejournet Extrusion Process. S. Sejournet. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, Paper L.68). [In English]. Recent developments in the process of steel extrusion are briefly reviewed. The individual operations involved, possible output of the press, field of application, and economics of the process are outlined.—V. G.

Extruded Rings for Gas Turbines. (*Aeroplane*, 1954, **86**, Apr. 2, 401–403). A description is given of the production by Chesterfield Tube Co., Ltd., and Reynolds Tube Co., Ltd., of extruded flash butt-welded precision rings in stainless heat-resisting steels. The alloy almost exclusively used for these rings at present is the titanium-stabilised, 18% chromium, 8–12% nickel stainless steel. Extrusions are, however, now being produced in the higher chromium-nickel alloys, some of which contain tungsten, and also in ferritic steels containing boron. The rings are bent in special roller bending machines and then automatically flash butt-welded. This is followed by stretching and then stiffening by air-cooling from 1500° C. Finally, the rings are set by hand to a tolerance of 0·020 in. on diameter and to a similar tolerance on flats.

Pneumatic Blank Holders. A. G. Arend. (*Tin-Printer and Box Maker*, 1954, **30**, Mar., 14–15). Blank holders for modern and for older types of drawing presses are described and their advantages are pointed out.—R. P.

The Rôle of the Laboratory in Steel Wire Manufacture. W. A. Sandilands. (*Wire Ind.*, 1953, **30**, Dec., 1177–1182). The functions of the works laboratory in the control of raw materials and processes, in research and development, and statistical control, and its roll in assisting the Sales Department and drawing up standards and specifications, are discussed and illustrated with examples from various stages of the manufacture of steel wire.—J. G. W.

ROLLING-MILL PRACTICE

Cluster Mills for the Cold Rolling of Strip. F. Wiesner. (*Hutnické Listy*, 1954, **9**, (3), 141–144). [In Czech]. An analysis of the principles and advantages of cluster mills for the rolling of thin sheet is made. The Rohn and Sendzimir types of stands are discussed.—P. F.

Thin Gauge Steel Rolled on Y-Mill in France. (*Blast Furn. Steel Plant*, 1954, **42**, Mar., 336–338). A description of a 20-in. reversing cold mill with a **Y** arrangement of the rolls, used to reduce basic-Bessemer strip from 0·0787 to 0·0197 in. in four or five passes, is given. The mill is at the Société Etilam of Jeumont, France, and was built by Mackintosh-Hemphill Co., Pittsburgh.—B. G. B.

Direct Rolling of Carbon Steel Ingots to Plates on 3-High and 4-High Plate Mills. R. C. McMichael. (*Iron Steel Eng.*, 1954, **31**, Mar., 91–98). This article describes the direct rolling of ingots to plates on the 3-high and 4-high mills at the Lukens Steel Co. A 3-high 112-in. mill which was producing plates until 1943 now serves as a roughing mill to a new 4-high 120-in. mill. There is a vertical 'edger' 40 ft. behind the 112-in. stand, and another 'edger' integral with and in front of the 120-in stand. A higher yield of high quality plate is obtained by rolling from ingots than by first rolling slabs in a slabbing mill. Rolling practice is described in detail and the defects encountered and methods of reducing them are fully dealt with.—R. A. R.

Study on the Oblique Rolling. (I). T. Ikeshima. (*Tetsu to Hagane*, 1951, **37**, Feb., 88–92 ; June, 341–344). [In Japanese]. An analysis was made of the operations of the Mannesmann type piercing machine. The axial slip between rolls and billet is higher than in normal rolling, and the power consumption is proportional to the deformation and degree of

piercing. Twisting of the pierced billet surface is less than the calculated value, as a result of peripheral slip, this is greatest in the centre of the pass and is far less than the axial slip.—K. E. J.

Thread Inserts Simplify Hot Mill Maintenance Problems. (*Iron Steel Eng.*, 1954, **31**, Apr., 144–146). The article describes a method of repairing stripped holes in 3-high roughing mills with wire screwthread inserts, eliminating costly damage to mill housings, reducing stoppages for maintenance by 66%, and automatically increasing production.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

Gas Turbines for the Steel Industry. G. H. Krapf. (American Power Conf. : *Iron Steel Eng.*, 1954, **31**, Apr., 97–100 ; *Blast Furn. Steel Plant*, 1954, **42**, Apr., 444–447, 450). The author discusses the possibilities of using gas turbines for power generation and for blast-furnace blowing. Reference is made to two steel plant blast-furnace-gas-fired turbines installed in Europe. The author concludes that it is time that someone should design, manufacture, install, and operate a gas turbine plant in an American steelworks.—M. D. J. B.

The Economics of Power Generation by Gas Turbine Power Plants. C. J. Burke. (*Blast Furn. Steel Plant*, 1954, **42**, Feb., 236–238 ; Mar., 356–358). The best design of gas turbine for generating electric power under particular conditions is considered. These conditions include continuous, intermittent, or standby operation.—B. G. B.

Gas Turbines for Power Generation. F. E. Baumann. (Cleveland Inst. Engineers: *Iron Steel Inst., Spec. Rep.* No. 49, 1954, 1954, Feb., 23–35). Some typical gas-turbine applications in ship propulsion, locomotives, electrical power generation, and in the iron and steel industry are reviewed. Attention is given to design, layout, and operating conditions, and to the use of gaseous, liquid, and solid fuels in the gas turbine.

Considerations Concerning the Choice of Electrical Equipment for the Iron and Steel Plants of Paz de Rio (Colombia) and Chimbote (Peru). R. L. Jung. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogota, Colombia, Oct. 13–Nov. 5, 1952, *Paper*, L.57). [In English].

John Summers & Sons Limited—Main Electrical Distribution. (*Iron Coal Trades Rev. Special Issue*,, 1953, Apr. 20, 70–72). Details are given of the main electrical distribution from the existing British Electricity Authority switchgear to the various parts of the new plant of John Summers & Sons Ltd.—G. F.

Control of Electric Power Systems in Steel Plants. K. S. Kuka. (*Iron Steel Eng.*, 1954, **31**, Mar., 105–112). The author discusses the power requirements of a large integrated works and describes the measures which are taken to meet these requirements.—M. D. J. B.

Research and Development in Electric Overhead Travelling Cranes for Steelworks. (*Brit. Steelmaker*, 1954, **20**, Mar., 96–99). An account is given of recent research and development work carried out by the B.I.S.R.A. Steelworks Cranes Sub-Committee. The work is concerned with three main problems, namely : Performance and specification ; controller design and cab layout ; and factors affecting design, such as crane stresses, gantry design, and motor performance. These aspects are discussed separately.—G. F.

Crane-Mounted Weighers: Methods of Ensuring Correct Wagon Loads. H. J. Burgess. (*Iron Steel*, 1954, **27**, Apr., 125–130, 132). The author considers mainly the weighing methods suitable for grabbing cranes, and hook suspension weighers, and also discusses other devices which might be adaptable for approximate weighing on cranes. The merits of the different types are compared, and recommendations are made on the types to be used in different applications.

Belt Conveyor Design. F. Lebeter. (*Coke Gas*, 1954, **16**, Mar. 107–110 ; Apr. 159–162). The basic principles in the design of belt conveyors and the factors affecting their operation and life are discussed. Details are given to show how the power required for the conveyor may be calculated and how the effects of friction may be minimized.—B. C. W.

Steelworks, Diesel-Electric Shunters. (*Oil Eng. and Gas Turb.*, 1954, **21**, Feb. 368–369). Details are given of two Diesel-electric shunting locomotives developed by the Yorkshire Engine Co. Ltd. and fitted with 6 cyclinder, and 12 cylinder, Davey Paxman oil engines and B.T.H. power units developing respectively 275 and 400 b.h.p. The smaller locomotive is an 0–4–0 and the larger is an 0–6–0 ; both are designed for heavy industrial use.—M. D. J. B.

LUBRICANTS AND LUBRICATION

The Influence of Oxide and Lubricant Films on the Friction and Surface Damage of Metals. W. Hirst and J. K. Lancaster. (*Proc. Roy. Soc.*, 1954, **A223**, May 6, 324–338). The protection against surface damage given by an oxide film during sliding of metals depends on the geometrical arrangements and their influence on the growth of metallic junctions. Breakdown loads exist above which friction and damage increase markedly; these are also found under boundary lubrication conditions. The interactions of oxide films, lubricant films and work-hardened layers are discussed. (18 references).—K. E. J.

Recent Advances in Modern Lubrication. I. A. Howden. (*Yearbook Coke Oven Man. Assoc.*, 1954, 253–261). The reasons for using additives in modern petroleum lubricants are discussed, and a functional description is given of anti-oxidants, detergents, corrosion preventives, rust preventives, metal passivators, anti-wear additives, extreme pressure additives, and foam suppressants. The particular uses of such additives are described with emphasis on the necessary compatibility of additives with the parent lubricant.—J. E. J.

Proceedings of the Second International Congress on Rheology. V. G. W. Harrison [Editor]. (Butterworths Scientific Publications, 1954). The Second International Congress on Rheology was held at Oxford on July 26–31, 1953. The papers on lubrication, which are reported in this 451-page volume, are:

Viscoelastic Behaviour of Lubricating Greases. J. F. Hutton and J. B. Matthews. (408–413).

The Rheological Properties of Lubricants. H. Umstätter. (414–426). [In German].

A Theory of Grease Lubrication of a Slider Bearing. A. A. Milne. (427–436).

Viscosity and Density of Lubricating Oils at High Pressures. L. Grunberg. (437–444).

WELDING AND FLAME-CUTTING

The Recent Arc Welding Electrodes. T. Mitsuhashi. (*Tetsu to Hagane*, 1951, **37**, Nov., 601–607). [In Japanese]. In view of the post-war importance of welding electrodes, recent data and specifications are presented for various types of electrodes produced in the U.S.A., Britain, and other countries.—K. E. J.

Comparison of the Production of Welded and Seamless Steel Tubes. G. Tichy. (*Berg. Hüttenmänn. Monatsh.*, 1953, **98**, May, 81–86). Recent developments in tube production in Western Germany and the U.S.A. are surveyed. Modern methods of tube welding are outlined and practices in the two countries are compared.—E. C.

The Inspection of Weldments. W. Kaufmann. (*Mét. Constr. Mécan.*, 1954, **86**, Mar., 203–221). A detailed account of methods used to check the soundness of equipment constructed by welding processes is presented. The design of the part to be made is first discussed and then details of methods used to test the suitability of the base metal for welding are given. The selection of electrodes is considered, and work carried out on the strength of welded materials is reviewed. The inspection of welded joints during production by X-ray radiography and the testing by destructive and non-destructive methods, of the final equipment are discussed. Examples of the types of defects found in welded joints are given.

The " Great Jib " of the W1400 Walking Dragline. A. Scott. (*Brit. Welding J.*, 1954, **1**, May, 197–205). Much research and development work was required for the evolution of the design and construction of the great jib of the walking dragline used to strip overburden at the ironstone quarries of Stewarts and Lloyds, Ltd. A special high-tensile steel was developed for the all-welded, tubular structure, of triangulated cross-section. Welding was carried out with a 0·5%-Mo electrode.

Arc Welding of Self Hardening Steels. H. Granjon. (*Rev. Mét.*, 1954, **51**, Apr., 221–232). Cracking constitutes the major problem in the cold welding of self-hardening steels. It can, however, be overcome, even in deep welds, by the use of austenitic electrodes, provided these can withstand the dilution with the base metal. Other important factors are the state of the electrodes, their melting characteristics and the conditions of welding. These influences are considered in the light of experiments with various nickel–chromium–

molybdenum steel electrodes which yield a partially ferritic deposit.—A. G.

Resistance Welding of Coated Steels. A Review of Information. J. E. Roberts. (*Brit. Welding J.*, 1954, **1**, May, 233–237). A review is given of published information on the resistance welding of steels with surfaces protected by metallic coatings, with the object of determining the factors which may required further investigation.—U. E.

Inert-Gas-Shielded Metal-Arc Welding of Low-Carbon Steels. G. C. Christopher and R. C. Becker. (*Welding J.*, 1954, **33**, Jan., 7–22). The applicability of various types of steel filler rods for the inert-gas shielded metal-arc welding was investigated.—U. E.

Inert-Arc Field Welding of Pressure Piping. R. T. Pursell. (*Welding J.*, 1954, **33**, Jan., 41–46). A description is given of the use of paper discs as backing strips in the inert-gas shielded arc welding process as applied to erection of pressure piping in the field.—U. E.

Aspects of Welding Research in British Merchant Shipbuilding. R. B. Shepheard. (*Welding J.*, 1954, **33**, Jan., 23–40). The importance of adequate notch toughness at service temperature in mild steel is stressed and a review is given of recent researches in welding aluminium alloys, residual stresses, and full-scale structural tests on welded and riveted ships.—U. E.

The Rôle of Aluminium as a Special Fuel. G. M. Babcock and F. B. Retwisch. (*Eng. Min. J.*, 1954, **155**, Mar., 84–86). A survey is made of the means of utilizing the exothermic oxidation of aluminium, including cutting and scarfing of metals, refractories or slags, powder lancing, the reduction of metallic ores, thermite welding, explosives and incendiaries, heating devices based on reaction with aqueous solutions, additions to clinkering coals, and types of hot tops for castings.—K. E. J.

Soldering with the Ultra-sonic Soldering Iron. (*Usine Nouvelle*, 1954, **9**, Jan. 14, 25–27). The equipment is described and its uses considered. Apart from the soldering of aluminium its use on other metals eliminates the need for flux and restricts the flow of solder to the joint alone. It is very suitable for mass production or the repair of cast parts.—A. G.

Sections Obtained by Cutting Small Beams. Courtheoux. (*Centre Doc. Sid., Circ. Inform Tech.*, 1953, (10), 1595–1606). Oxygen lance cutting makes it possible to convert girder sections into more useful sections. The available methods of cutting (longitudinal, assymetric, and diagonal) and the need for a final straightening process are considered.—A. G.

Jigs and Fixtures for Oxy-Acetylene Cutting. H. von Hofe. (*Schweissen u. Schneiden*, 1954, **6**, Apr., 145–154). A description is given of oxygen cutting with illustrations of jigs and equipment for cutting flat and curved surfaces.—U. E.

Modern Equipment for Oxygen Cutting. L. Bothorel. (*Mét. Constr., Mécan.*, 1954, **86**, Mar., 193–201). A detailed account of modern oxygen cutting equipment is given. The design of blowpipes for special operations is first considered. The addition of substances (alkaline flux, silica, iron) for cutting high-alloy and stainless steels is discussed and new equipment for accurate profile cutting is reviewed. Some modern machines for oxygen cutting are described.—B. G. B.

MACHINING AND MACHINABILITY

The Machinability of Steels as a Function of Heat-Treatment. I.—Mechanical Properties and Structures of the Steels Investigated. H. J. Wiester. (*Stahl u. Eisen*, 1954, **74**, Apr. 22, 526–530). The mechanical properties and microstructures of the steels after heat-treatment were shown to be those required and that the materials were uniform over the regions involved in the machining tests.—J. P.

The Machinability of Steels As a Function of Heat-Treatment. II—Effect of Heat-Treatment on the Main Cutting Power in Turning. O. Kienzle and H. Victor. (*Stahl u. Eisen*, 1954, **74**, Apr. 22, 530–539). The dependence of the main cutting power at various feeds, depths of cut and cutting speeds on six steels, as received and after soft annealing, normalizing, a coarse-grain anneal and heat-treating has been determined. The design and mode of action of the cutting moment meter are described. The specific cutting power hardly varied with the different heat-treatments. Only the heat-treated steels required a slightly higher power. The simple cutting power equation for the practical calculation of the cutting power depends on the design and condition of the lathe and on cutting speed.—J. P.

The Machinability of Steels As a Function of Heat-Treatment. III—Effect of Heat-Treatment on the Machinability in Turning and Boring with High-Speed Steel Tools. W. Leyensetter and E. Kaluza. (*Stahl u. Eisen*, 1954, **74**, Apr. 22, 540–551). The effect of heat-treatment of the steels on tool life measured in various ways, on the chip upset, turning moment, and temperature of the tool tip during turning and boring is discussed and related to steel structure and mechanical properties.—J. P.

Guide for Machining Stainless Steels. J. D. Armour. (*Steel*, 1954, **134**, Mar. 22, 92–95; Mar. 29, 106–110). Data on the proper conditions for forming, drilling, tapping, threading, reaming, and milling stainless steels are given. In the second part, machining troubles and suggested causes are tabulated.

Machining Powder-Metal Parts Is Easy if Tools Are Dead Sharp . . . A. J. Langhammer and P. Glick. (*Machinist*, 1954, **98**, June 12, 1037–1040). Methods of machining fairly porous powder-metal parts are described. High surface speeds, fine feeds and sharp tungsten carbide tools with correct clearance and cutting angles are recommended.—M. A. K.

Central Coolant System Offers Savings Benefits. E. C. Beaudet. (*Iron Age*, 1954, **173**, Feb. 11, 127–130). A centralized system for supplying and purifying water-soluble oils for grinding and cutting operations is described. A recovery of 99% is claimed.—A. M. F.

Relations between the Fibrous Structure of Turnings during Machining, Determined by X-Rays and the Mechanism of Deformation in the Cutting of Metals. P. Bastien and M. Weisz. (*Compt. Rend.*, 1954, **238**, Apr. 12, 1583–1585). An X-ray and micrographic study has revealed the relation between the 3 main variables in the cutting process, namely ϕ, the angle of the limiting plane of stable equilibrium, τ, the angle of friction, and α the cutting angle. For face-centred cubic metals $\phi + (\tau - \alpha) = 54° 44'$ with the axis making an angle [111] with the (110) plane.—A. G.

Hydraulic Roll-Turning Lathe. B. A. Wilson. (*Ing. e Indust.*, 1954, **22**, Jan.-Feb., 91–92). [In Spanish]. A description and sketch are given together with quantitative details of what this 60-in. machine can do. It saves up to 75% machining time.—C. B. L.

Examination by the Electron Microscope of the Mechanism of Superfinishing. N. Takahashi and T. Asaeda. (*Métaux-Corrosion-Indust.*, 1954, **29**, Mar., 95–99). An investigation of the process of obtaining a super finish (maximum surface projection 1μ) on the surface of metals, using electron microscopic techniques is reported. The mechanism of grinding has been studied and microphotographs showing the surface of a high chromium steel before and after treatment are reproduced.—B. G. B.

Report on Electro-Erosion Machining. (*Machinist*, 1954, **98**, May 15, 833–834). The application of this technique to the toolmaking industry enables carbide dies to be produced without splitting the form, and steel to be machined in its hardened state.—M. A. K.

The Exsel Disintegrator. (*Usine Nouvelle*, 1953, **9**, Dec. 3, 53). A hollow electrode carrying a heavy current makes contact with the part to be disintegrated 30 times/sec. while water is directed down the inside. Hard materials impossible to machine can be treated and broken taps removed without damage to the threads already formed.—A. G.

CLEANING AND PICKLING

Experiments with Abrasives for Blast Cleaning. W. Gesell. (*Giesserei*, 1954, **41**, Apr. 1, 160–163). The working life of grains of different sizes for blast cleaning are first considered. Life curves for grit and shot of different grain size are compared and indicate that considerably more scatter is obtained in the life of the grit. To clarify this a series of experiments is proposed. The abrasive is tested with regard to its working life, its cleaning effect, and the wear it causes on the ejector. The author proposes units to measure these effects.—R. J. W.

Cleaning Metal with Sonic Waves. I. J. Kearney. (*Steel*, 1954, **134**, Apr. 5, 104–105). The working of plant for cleaning parts, including difficult shapes, is described. Radio-frequency 0·75 to 5 kW. generators operate treated barium-titanate transducers, which generate ultrasonic waves in a chlorinated cleaning solvent into which the work is placed.—D. L. C. P.

Microstructure and the Corrodibility of Steel in Inhibited Hydrochloric Acid Solutions. P. H. Cardwell. (*J. Electrochem. Soc.*, 1954, **101**, Feb., 84–90). Weight loss tests of 0·15–0·35% C steels in two inhibited 10% HCl solutions have

been determined after various heat-treatments. The resolution of pearlite, grain size, and presence of Widmanstätten structure have considerable influence on the corrosion rate.

Testing the Efficiency of Pickling Inhibitors. G. Hoff and G. van der Dunk. (*Arch. Eisenhüttenwesen*, 1954, **35**, Mar.-Apr., 115–123). An apparatus is described by which the effect of inhibitors in reducing acid attack on mild steel can be assessed from the volume of gas formed. A separate test is used to determine the time required for removal of scale from oxidized samples. It is shown that commercial inhibitors differ appreciably in their efficiencies and their stabilities; in general, those which are highly efficient increase pickling time somewhat. The influence of dissolved iron salts in H_2SO_4 and HCl baths, with and without inhibitors, on acid attack on steel and on pickling time has been measured. With good inhibitors, dissolved iron makes little difference to acid attack, but it increases pickling time. Special tests in H_2SO_4 at 95° C. have shown how pickling time varies with acid and iron concentrations. Minimum pickling time is found at 30 wt.-% of acid in absence of dissolved iron and at progressively decreasing concentrations as the iron content increases; the minimum time with 100 g. iron per litre is at 15% acid, but this minimum time is nearly twice as long as with iron-free acid.—J. P.

Corrosion Inhibition in Acid Solution. C. V. King and E. Hillner. (*J. Electrochem. Soc.*, 1954, **101**, Feb., 79–83). Rotating cylinders of iron, zinc, and cadmium were immersed in depolarized solutions containing 0·02M HCl; 0·06M KNO_3 plus inhibitors which were of the following types: (*a*) dichromate ion with complexing agent for metal ions, (*b*) a strongly adsorbed wetting or emulsifying agent, and (*c*) a reagent which forms insoluble precipitate with iron ions. The effectiveness of the inhibitors is discussed.—A. D. H.

Chemical Polishing of Steel. W. A. Marshall. (*Research*, 1954, **7**, Mar., 89–93). The surfaces of ferrous materials may be smoothed or even polished by a new chemical method employing oxalic acid, H_2O_2, and H_2SO_4 in solution (the 'A.R.E. smoothing process' developed by the Armament Research Establishment). This has certain advantages over electropolishing, and has applications to engineering and decorative manufactures, though limits are imposed by economic considerations.—K. E. J.

Some Physical Effects in Polishing. S. G. Red'ko. (*Stanki i Instrument*, 1954, (1), 13–15). [In Russian]. Experiments on the polishing of steel and other specimens under various conditions are described and the corresponding thermal conditions are discussed.—S. K.

The Regeneration of an Electrolyte for Polishing Steel. N. P. Fedot'ev, E. G. Kruglova, and S. Ya. Grilikhes. (*Zhurnal Prikladnoi Khimii*, 1954, **27**, (2), 157–165). [In Russian]. Causes of deterioration of an electrolyte (a mixture of phosphoric, sulphuric and chromic acids) used for polishing steel and methods of regenerating it were investigated. Deterioration during use is caused by a decrease in the concentration of the passivator (CrO_3), and complete stoppage due to the accumulation of iron (above 6% of Fe_2O_3). The quantitative reoxidation of Cr_2O_3 is obtained by anodic oxidation, using a lead electrode covered with a lead dioxide film in an electrolyte containing not less than 6% of H_2SO_4. Optimum conditions of anodic oxidation are: Current density, anodic 3–5 amp./sq. dm., cathodic 5–10 amp/sq. dm.; electrolyte temperature, 20–25° C. The used electrolyte can be regenerated by cathodic reduction of sexavalent chromium and trivalent iron, and the precipitation of the divalent iron formed as a sulphate. Optimum regenerating conditions are: Volume current density 0·7–1·0 amp./litre, cathodic: 5–10 amp./sq. dm.; electrolyte temperature 70–80° C.—V. G.

PROTECTIVE COATINGS

Hard Chrome Plating Made Easy. E. A. Blount. (*Products Finishing*, 1953, **18**, Dec., 24–36). The practice of an American firm specializing in the hard chromium plating of moulding dies for plastics is described. Special attention is paid to the surface preparation before plating. The firm's methods of plating aluminium and brass with bright nickel and chromium are also detailed.—A. D. H.

Hard Chromium Plated Shafts for Plain Bearings. O. Gersdorfer. (*Maschinenwelt u. Elektrotechnik*, 1954, **9**, Mar., 75–77). After discussing the properties and advantages of hard chromium plating as a bearing surface, the author describes experiments using hard chromium plated shafts in plain bearings.—L. D. H.

Bright Nickel Plating. (S. E. and M. Vernon Co.) (*Product Finishing*, 1954, **7**, Jan., 66–70). The 'Nickel-Lume' process is described and bath compositions are given.—A. D. H.

A Commercial Gas Plating Process. (*Electroplating*, 1954, **7**, Jan., 16–18). The decomposition of nickel carbonyl at 200° C. deposits a film of nickel on metallic and non-metallic surfaces. The development of a commercial process by an American firm is described. The high speed of deposition and deposition on large surfaces are outstanding features.

Hot Dip Galvanizing. K. S. Frazier. (*Steel*, 1954, **134**, Feb. 22, 102–103; Mar. 1, 98–99; Mar. 8, 138–139). Part 1 deals with control of the coating thickness and gives an account of some submersion tests. Part 2 is concerned with the control of dross formation and wear on the kettle, and Part 3 describes the suitability of some materials for dipping and the surface preparation of work.—D. L. C. P.

A Nail Galvanizing Machine. (*Wire Ind.*, 1953, **20**, Dec., 1193). A machine manufactured by Morrison Industries Inc. Cleveland, Ohio, for galvanizing nails in batches of 600–1000 lb. is described and illustrated.—J. G. W.

Radiometric Study of Supplementary Chromate Coatings for Zinc and Cadmium Plating. S. L. Eisler, J. Doss, and M. A. Henderson. (*Plating*, 1954, **41**, Feb., 147–154). Radioactive isotopes of chromium and sulphur have been used to determine the amounts of SO_4 and chromium in coatings produced by supplementary dip solutions. The amount of sulphate and chromium in the coating increases, but not proportionally, with the amount of sulphuric acid in the dip solution. The loss of chromate was much slower than that of the sulphate. Nitrate-containing solutions have no advantage over those containing sulphate.—A. D. H.

John Summers & Sons Limited—Processing and Galvanizing at "Marsh" Plant. (*Iron Coal Trades Rev., Special Issue*, 1953, Apr. 20, 89–93). The "Marsh" plant of John Summers & Sons Ltd. processes coil and sheet for specific purposes. Coil is galvanized by the Sendzimir process, and sheet is pickled, cold-rolled, and annealed. Brief descriptions are given of the plant and of these processes.—G. F.

John Summers & Sons Limited—Electro-Deposition. (*Iron Coal Trades Rev., Special Issue*, 1953, Apr. 20, 93–95). A brief description is given of the two new zinc electro-deposition plants of John Summers & Sons Ltd., dealing with sheets up to 42 in. and 54 in. wide respectively. The processes in sequence are degreasing, pickling, plating, and, if necessary, phosphatizing and chromate rinsing, all in the same line.

Animal Fats in Hot Dip Tinning. C. F. Gurnham. (*Products Finishing*, 1954, **18**, Jan., 48–64). Eight different animal fats have been evaluated as substitutes for palm oil in tinning. A hydrogenated grease containing 8–9% fatty acids was found to be most suitable and a detailed specification is given.

General Considerations on the Manufacture of Tinplate. L. Gascuel. (*Mét. Constr. Mécan.*, 1954, **86**, Feb., 133–135). The properties and method of preparation of tinplate are discussed. The modern continuous methods of hot-dip tinning and electrolytic tinning are described. The different qualities of tinplate produced and various finishing techniques which are used are reviewed.—B. G. B.

Production Tin-Zinc Alloy Plating. A. Whittaker. (*Machinery*, 1954, **84**, Mar. 26, 639–642). The article describes a process developed by The Tin Research Institute for commercial application of tin-zinc alloy plating. The characteristics of 80/20 tin-zinc alloy deposits and the effects of temperature, current density, solution composition, and concentration, impurities, and anode composition are discussed.—M. A. K.

The Dependence of the Refractoriness of a Low-Carbon Aluminized Steel on the Method of Cladding. T. Drazkiewicz and S. Gebalski. (*Prace Instytutow Mechaniki*, 1953, **3**, (9), 16–40). [In Polish]. Methods of covering steel with a protective diffused aluminium layer are surveyed. Experiments in producing an aluminized protective layer on an ordinary low carbon steel (C −0·15%) and the dependence of the protective properties on the method of covering are described. The following covering methods are tested: (1) Cementation in powders, (2) dipping into molten aluminium, (3) cladding by rolling, (4) electroplating, (5) gaseous diffusion, and (6) spraying with subsequent heat-treatment. Heat resistance tests were made at 400, 700 and 950° C. on samples covered by methods (1), (2), and (6). The results showed that at 700° C.

and particularly at 950° C. method (6) is superior to other methods. At 400° C., samples covered by the above three methods showed similar refractory properties.—V. G.

Electrodeposition of Lead on Steel. The Broken Hill Associated Smelters Pty. Ltd. (*Chem. Eng. Min. Rev.*, 1953, **46**, Nov. 10, 49–50). A procedure is described whereby lead is deposited on steel sheet previously coated with lead–nickel alloy by the hot-dip process developed by the British Non-Ferrous Metals Research Association. The dipped sheet is made the cathode in a solution containing 40–50 g./l. of caustic soda. A steel anode and c.d. of about 30 amp./sq. ft. cathode area are used. A standard fluo-borate bath is applied for the plating treatment.—R. A. R.

Sealing Metal Surfaces with Resins. A. E. Williams. (*Indust. Finishing*, 1954, **6**, Apr., 635–641). The ethoxyline resins (manufactured as "Araldite" by Aero Research Ltd.) are used for sealing aluminium and magnesium alloys, bronzes, and ferrous metals. Their chemical and physical properties, and methods of use, are described. They are used as primers or single coatings for containers for foodstuffs, domestic equipment, for chemical engineering plant, and for aircraft parts. Some cost figures are given.—K. E. J.

Where Asphalt Coatings Are Used. G. Benn. (*Mat. Methods*, 1954, **39**, Feb., 142–144). Asphalt coatings applied in the form of an emulsion, in which the emulsifying agent is a type of mineral colloid, will not flow under heat, crack in cold temperatures, or progressively oxidize from internal molecular flow when exposed to sun and weather, as do normal asphalt mixtures. The uses of such coatings as corrosion resistors and insulators on metal structures and plant are briefly reviewed.—P. M. C.

A Radiometric Study of the Iron Phosphating Process. S. L. Eisler and J. Doss. (*Metal Finishing*, 1954, **52**, Mar., 60–63). The amount of $FePO_4.2H_2O$ in phosphate coatings prepared from solutions of phosphoric acid, sodium dihydrogen phosphate and a commercial preparation was determined radiometrically. The coatings were found to consist of $< 35\%$ iron phosphate; the remainder was probably γ-Fe_2O_3. Immersion treatments generally produced more phosphate than the commercial spray treatment.—A. D. H.

Testing Organic Finishes and Interpretation of Results. C. O. Hutchinson. (*Plating*, 1953, **40**, Nov., 1255–1267). Over 60 properties of organic finishes used as a basis for evaluating of coatings are described. Standard American test procedures are recorded. (141 references).—A. D. H.

Sprayed Metallic Coatings. H. Reininger. (*Metal Ind.*, 1954, **84**, Mar. 26, 251–253; Apr. 2, 265, 266; Apr. 9, 291–293). Recent literature dealing with the mechanism of formation, structure, and application of sprayed metallic coatings is discussed at some length. The current belief that the particles of sprayed metal are solidified, or at least are of a paste-like constituency, by the time they strike the surface is examined and the texture, structure, and adherence of sprayed coatings are discussed. Surface preparation by degreasing, sand and grit blasting, and etching is described, and the connection between surface treatment and strength of adhesion is summarized. Finally, after-treatment of coatings by thermal, mechanical, and chemical processes, and the resulting improvements in properties are described. (83 references).

Metal Spraying for Corrosion Protection. C. A. Robiette. (*Indust. Finishing*, 1954, **6**, Mar., 564–573). A review of the subject covers the pistols used, quality of the coatings, base metal preparation, the mechanism of protection, sealing of the coating, coating thicknesses, the resistance of various sprayed metals (mainly Zn and Al) to atmospheres and salt and neutral water, temperature effects, and many industrial applications.—K. E. J.

Adhesion and Surface Preparation in Protective Metal Spraying. J. M. Cowan. (*Electroplating*, 1954, **7**, Feb., 79–82; Mar., 117–122). The adhesion of sprayed metals is discussed and methods of measuring adhesion are reviewed. The effect of variations in grit-blasting conditions, the basis metal, and the spraying conditions are described.—A. D. H.

American Processes for Metallizing. L. Butor. (*Arts et Manuf.*, 1954, Feb., 11–15). The application of coatings of protective metals by atomizing the metal in a flame is discussed. A number of examples of this technique is considered. These include anti-friction coatings of bronze, anti-corrosive coatings of zinc, aluminium, and stainless steel, and decorative finishes of aluminium.—B. G. B.

Electrostatic Spraying of Porcelain Enamel. M. L. Pouilly. (*Products Finishing*, 1953, **18**, Dec., 40–48). Recent improvements in the electrostatic spraying process for titanium enamel are described. Changes in spray design and the addition of sodium nitride have been found to improve atomization. Overhead conveyors give the best results using a modified frit formulation.—A. D. H.

Special Coatings for Metals Used at High Temperatures. A. H. Sully. (*Product Eng.*, 1954, **25**, Jan., 135–141). Surface impregnation with diffusion coatings, refractory coatings and low emissivity coatings as surface treatments for high temperature working are discussed. Diffusion coatings cover aluminium, silicon, and chromium, the latter giving wet corrosion resistance as well as high temperature scale resistance. Refractory coatings consist almost entirely of protective enamels which can be used at 1800° F. Low emissivity coatings are not in themselves oxidation protective, as they rely on their porosity to provide low emissivity. The coatings are primarily oxides of alumina and magnesia.—A. M. F.

Ceramic-Coated Metals for Industry. B. W. King. (*Battelle Tech. Rev.*, 1954, **3**, Apr., 39–42). After outlining the method of applying ceramic coatings to metal, the author discusses the physical, chemical, and mechanical properties of such coated materials. Cermet coatings are not considered. The nature of the ceramic-metal bond is dealt with and the precautions to be observed in order to develop satisfactory adherence are indicated.—L. E. W.

Flame Spraying Ceramics. T. A. Dickinson. (*Ceramics*, 1954, **5**, Jan., 512–515). The employment of flame spraying for coating metals, including aluminium, magnesium, titanium, iron, and steel with ceramic oxides is described. At present the development is largely confined to work for use at normal temperatures, as available coatings have different thermal expansion characteristics from the metals.—D. L. C. P.

Ceramics for High Temperature Applications. A. Pechman. (*Ceramics*, 1954, **6**, Mar., 19–27). The properties of ceramic coatings and cermets are surveyed and examples of their high temperature applications given.—D. L. C. P.

Resistance of Vitreous Enamel to Bleaching Agents. J. R. Crandall, J. C. Richmond, and W. N. Harrison. (*Product Finishing*, 1954, **7**, Jan., 71–73). A brief summary is made of the results of studies at the U.S. National Bureau of Standards on the resistance of vitreous enamels to hypochlorite bleaches. Photometric and plastic replica techniques were used.—A. D. H.

Study of Strains Between Enamel and Iron as Related to Physical Properties of Each. J. D. Walton, jun. (*J. Amer. Ceram. Soc.*, 1954, **37**, Mar., 153–160). The results of three test methods for measuring strains between enamel and iron are correlated with the mechanics of the systems, and, it is shown that they can be inter-related. The stresses responsible for the strains obtained by the split-ring test may be calculated and the effect of the thicknesses of enamel and iron on the variation of compressive forces within the enamel are estimated.—D. L. C. P.

Production of Vitreous-Enamelled Iron Castings. A. Adam. (Inst. Brit. Foundrymen: *Found. Trade J.*, 1954, **96**, Mar. 4, 249–254). The troubles arising when castings are enamelled are summarized and the problem of blistering is discussed. Recent work has shown that many of the theories of blistering cannot be substantiated, and it is concluded that the process involves two stages: (1) A reaction between casting surface and mould; and (2) a reaction between casting surface and mould; and (2) a reaction between casting surface and water vapour in the enamelling muffle. Blistering may be almost completely eliminated by reducing the concentration of water vapour in the muffle to below $0{\cdot}5\%$ by volume, and a patented method for doing this is described. Castings made by the shell-moulding process do not suffer from blistering.

Paints Incorporating Natural Rubber. (*Corrosion Prevention and Control*, 1954, **1**, Apr., 105–112). This is a review, by the Rubber Development Board in co-operation with a number of firms and authorities, of the potential uses of rubber-based paints from the point of view of their resistance to corrosion and chemical action.—L. E. W.

Paint Specifications for Metal Products. P. E. Marling. (*Product Eng.*, 1954, **25**, Mar., 173–181). Recommendations for synthetic finishing resins and application procedures for eight major classes of industrial products are made. Selection depends primarily on the properties such as colour retention, adhesion, flexibility, hardness, and heat resistance that are required.—A. M. F.

POWDER METALLURGY

Die Castings v. Sinterings. H. K. Barton. (*Machinery*, 1954, **84**, Apr. 30, 918–923). A comparison of the properties, potentialities, fields of application, and inherent limitations of die castings and sintered products has been attempted. The effect of pressure on compact density, advantages of infiltration, and accuracy of sintered products are discussed.

The Investigation of Sintering Processes by the Emanation Method. H. Schreiner and G. Glawitsch. (*Z. Metallkunde*, 1954, **45**, Mar., 102–108). By mixing the material to be sintered with a radioactive substance, and measuring α-radiation from the emanation of radioactive gaseous disintegration products at various temperatures, information was obtained in the form of a continuous record of the sintering process. Metal powders and mixtures, and the compacted substances were compared. The apparatus is described and the results evaluated.—L. D. H.

Static and Dynamic Measurement of the Elastic Modulus of Sintered Materials. J. Barducci and R. Cabarat. (*Rev. Mét.*, 1954, **51**, Mar., 149–153). The results of dynamic measurements (utilizing longitudinal vibrations) and static ones (at very low stresses) on sintered materials are discussed. Except for materials of very high porosity, the static and dynamic moduli are almost identical.— A. G.

Sintering and Diffusion Phenomena in the Nickel–Molybdenum–Iron System. F. Benesovsky. (*Proc. International Symposium on the Reactivity of Solids*, Gothenburg, 1952). [In German]. Mixtures of coarse-grained metal powders were pressed and sintered to study diffusion in the Ni–Mo, Fe–Mo, Fe–Ni, and Ni–Mo–Fe systems. In particular, the properties and structure of a 58/20/22 Ni–Mo–Fe alloy were examined using very pure raw materials. By sintering for 8 hr. at 1150° C. and then deforming, a dense and homogeneous material was obtained.—R. A. R.

Compacting and Sintering of Metal Powders on the Basis of Their Electrical Conductivity. V. I. Likhtman and L. Y. Nazarov. (*Zhurnal Tekhnicheskoi Fiziki*, 1952, **22**, (4), 696–702). The formation of contact surfaces during the pressing and sintering of metallic powders and the influence of surface active lubricants during pressing were investigated. Electrical conductivity measurements were used on the assumption that, at least during pressing, this property is a function of the size, character, and number of areas of contact. The following metal powders were tested : Electrolytic copper, electrolytic iron, iron obtained by reducing scale, and lead. As surface active lubricants oleic acid solutions in petroleum and in benzene were used.—V. G.

Fundamental Study and Equipment for Sintering and Testing of Cermet Bodies: VI, Fabrication, Testing, and Properties of 72 Chromium—28 Alumina Cermets. T. S. Shevlin. (*J. Amer. Ceram. Soc.*, 1954, **37**, Mar., 140–145). The physical properties of this cermet indicate the potential value of the material in high stress applications at elevated temperatures, where severe thermal shock may be encountered. Pore-free bodies of density 5·9 g./c.c. can be fabricated and may be useful in jet engine parts operating near 2000° F.—D. L. C. P.

Pore-Size Distribution of Porous Iron. P. Zwietering and H. L. T. Koks. (*Nature*, 1954, **173**, Apr. 10, 683–684). The difference in the specific volumes in mercury and helium has been used to calculate the total pore volume of two samples of porous iron. Surface areas calculated from the Brunauer-Emmett-Teller isotherm and from the pore size distribution curve are in good agreement.—A. G.

PROPERTIES AND TESTS

Creep and Relaxation. H. Umstätter. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, June, 184–191). Starting from Maxwell's relaxation theorem, a general theory of relaxation and creep is developed. A sensitive electrical relaxation testing device for steel wires is described in which a change of tension on the wire due to relaxation is detected by a change in natural frequency of vibration.—H. R. M.

Creep Strength and Embrittlement of Ferritic Steels at 550° C. E. Theis. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, Oct., 300–315). Creep tests were carried out at 550° C. on plain and notched specimens of ferritic Cr–Mo–V steels which might be used for high temperature steam plant. Three groups of steels, with about 1·3%, 3–6%, and 13% Cr respectively, with various heat-treatments, were tested. Notched-bar impact tests showed that these steels became embrittled during the creep tests unless the chromium content was at least 5%.—H. R. M.

A Statistical Study of the Creep and Fatigue Properties of a Precision-Cast High-Temperature Alloy. G. T. Harris and H. C. Child. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 284–290). [This issue].

Behaviour of Metallic Materials at Sub-Zero Temperatures. M. Torrado Varela. (*Tecn. Met.*, 1953, **9**, Feb., 37–45). [In Spanish]. The physical and chemical characteristics of the stratosphere are described. Anisotropy and its effects at low temperatures are considered. The influence of stratospheric temperatures (— 50° to — 60° C.) on the mechanical properties of steels, aluminium, and magnesium alloys is described. In view of the dryness, low density, and low temperature of the stratosphere, corrosion and corrosion fatigue are less to be feared than at ground level. At temperatures in the above range, the elastic limit and breaking loads of many materials increase. Tin is an exception. At still lower temperatures, there are other exceptions to this tendency, including stainless steels. The impact strength of notched specimens increases slightly in the case of face-centred cubic structures and decreases in those materials which do not possess this structure, especially low-carbon steels. The fatigue limit is not diminished at stratospheric temperatures in structural alloys, and it undergoes a marked increase in materials susceptible to age-hardening. The physical changes promoted by sub-zero treatment are reversible on return to normal temperatures (except in the case of tin).—R. S.

Properties of Low-Carbon Structural Steels Alloyed with Phosphorus and Copper. Part II—Oxidation Behaviour at Elevated Temperatures. N. Collari and N. Fongi. (*Met. Ital.*, 1954, **46**, Apr., 111–122). The oxidation and scale-forming tendency of a number of steels with carbon up to 0·07%, phosphorus up to 0·214%, and copper up to 1·15% was investigated. Phosphorus is more efficient than copper in reducing oxidation. The proportion in which the two elements are present together determines whether oxidation is increased or decreased. The oxidizing rate increases very rapidly with rising temperature after 800° C. has been reached.—R. A. R.

Correlation of Rupture Data for Metals at Elevated Temperatures. R. L. Orr, O. D. Sherby, and J. E. Dorn. (*Trans. Amer. Soc. Metals*, 1954, **46**, 113–128). It is shown that stress-rupture data for pure metals and high strength alloys at elevated temperatures can be correlated by the equation

$$t_r e^{-\Delta H_r/RT} = f(\sigma)$$

where σ is the applied stress, T is the absolute temperature, t_r is the time to rupture, R is the gas constant, and ΔH_r is the activation energy for rupture. Twenty-four commercial alloys, mostly iron-base, were analysed by this equation yielding good correlations. This permits the prediction of rupture-strength characteristics over wide ranges of conditions from a limited number of tests. ΔH_r was found to be constant for a given metal, and for most of the alloys was about 90,000 cal./mole.—D. L. C. P.

Low-Cost Alloys Offer Good Heat Resistance. R. W. Boring. (*Iron Age*, 1954, **173**, Feb. 18, 137–141; Mar. 11, 146–148). The effects of alloying elements in Amer. Iron Steel Inst. 330, 310, 309, 430 and 446 types of stainless steel are described. By careful selection these should take the place of more expensive materials. In particular 330 with 35–36% Ni has an extremely low coefficient of expansion and has proved outstanding for many heat-resisting applications. Recommended design stresses for this material for use between 1450° and 2100° F. are given.

Alpha-Molybdenum Hot-Work Die Steels. R. B. Corbett, J. A. Succop, and A. Feduska. (*Trans. Amer. Soc. Metals*, 1954, **46**, 1599–1618). The properties of several alpha-molybdenum steels were investigated for possible application as hot-work die blocks. The materials were found to be outstanding in their age-hardening tendency and resistance to heat checking. Experimental die blocks in three analyses were investigated. Steel containing 0·2% C; 3·0% Ni; 3·0% Mo as a hot-work die material in press and upsetter forging operations, gave production increases and had very good dimensional stability.—D. L. C. P.

Effect of Hardening Temperature on the Strength of R9 High-Speed Steel. E. I. Malinkina. (*Stanki i Instrument*, 1953, (12), 21–23). [In Russian]. In the investigation

described specimens of a high-speed steel (0·91% C, 4·2% Cr, 9·3% W, 2·1% V, 0·17% Mo) were subjected to various heat-treatments followed by mechanical tests. The strengths under twisting, tension, deflection, and impact were found to fall sharply with increasing hardening temperatures, those recommended being 1190–1200° C.—S. K.

High-Speed Steels, Their Origin, Development and Prospects. (*Aciers Fins et Speciaux*, 1954, **16**, Feb. 23–27). A short survey of the development and uses of high-speed steels is given.—V. G.

Defects in High-Speed Steels. Michel. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (11), 1771–1777). The following characteristics of high-speed steels render them liable to defects: A low conductivity due to their high alloy content; the resistance of molybdenum and tungsten to deformation; the presence of insoluble carbides; and a low melting point (1200–1350° C.). Precautions necessary include the avoidance of sudden temperature changes, gradual forging preceded by homogenization at 1150° C. and the careful control and organization of production.—A. G.

Study on Steels for High Pressure Vessels (I). F. Abe, T. Taniguchi, and T. Saito. (*Tetsu to Hagane*, 1951, **37**, Nov., 589–595). [In Japanese]. Vessels which had been in use for ammonia synthesis for 20 years were tested for changes in composition, microstructure, mechanical properties, and gas adsorption. Nickel–chromium steel was found to be in good condition in the vessels, although the upper covers had been attacked by the hot, high-pressure gases.—K. E. J.

The Diffusion of Nitrogen in Alpha Iron. W. R. Thomas and G. M. Leak. (*Phil. Mag.*, 1954, **45**, June, 656–659). Results are reported for a determination of the diffusion coefficient of nitrogen in α-iron by the change of internal friction, in the range 0–100° C. They are compared with the earlier determinations by Wert and Fast.—K. E. J.

Evaluation of Diffusion of Hydrogen into Iron by Observation of Linear Expansion of a Sample. M. Smialowski and Z. Szklarska-Smialowska. (*Bulletin de l'Académie Polonaise des Sciences*, 1953, **1**, (3–4), 159–163). [In English]. An apparatus is described for studying the penetration of hydrogen into iron and steel by measuring the linear expansion of a fine wire under the action of nascent hydrogen. Curves show the effect of raising the temperature of the solution of the 1*N* H_2SO_4 and of small additions of thio-urea.—R. A. R.

The Temperature Dependence of the Decarburization of Steel by Hydrogen. K. Lücke. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 181–185). The decarburization rate of carbonyl iron wires, containing a little carbon, during annealing at 610° and 715° C. in moist hydrogen, was measured by following the change of electrical resistance. In addition, exact calculation of the decarburization was carried out on the assumption that reaction between carbon and hydrogen took place only at the wire surface and that carbon was brought from the interior only by diffusion. The measurements were quantitatively accounted for by these calculations and the assumptions were thus confirmed. There was similarly agreement between calculated and determined decarburization rate and growth of the ferrite surface layer during treatment of γ-iron at 735° and 800° C. the final thickness (s) of the ferrite layer was given by $s^2 = 2D_aC_a/C_A$, where D_a and C_a are the diffusion coefficient and limiting solubility of carbon in α-iron, and C_A is the initial carbon content of the γ-iron. The greatest decarburization rate is predicted theoretically and found experimentally to be at a temperature of about 800° C.

Absorption of Hydrogen in Austenitic Steels during Cathodic Charging. F. Eisenkolb and G. Ehrlich. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 187–194). Austenitic steels, an iron–nickel alloy, pure nickel, and an unalloyed steel have been cathodically charged with hydrogen and the influence of electrolyte, small additions of arsenic, lead, sulphur, and selenium, the electrolysis conditions, and the conditions of the specimens were studied. The amount of hydrogen absorbed and the resulting embrittlement were measured. The results showed that austenitic steels absorb hydrogen during cathodic charging, particularly when certain additions, which have been shown to be active also with ferritic materials, are present. On the contrary, it was found that austenitic steels were not permeable to hydrogen. From the comparatively small embrittlement of the purely austenitic specimens, and the rapid loss of hydrogen, it was concluded that almost all the absorbed hydrogen was contained within the surface layer. Permanent change could not be detected. Surprisingly, it was found that after prolonged charging, the amount of absorbed hydrogen generally decreased. Cold worked or annealed specimens were much embrittled by hydrogen charging.—J. P.

Studies on the Heat Treatments of Constructional Alloy Steels. T. Kawai and K. Ogawa. (*Tetsu to Hagane*, 1951, **37**, Jan., 153–158; Apr., 216–233). [In Japanese]. Oil-quenched Mn–Cr, Mn–Cr–Mo, Si–Mn–Cr, and Ni–Cr steels showed low resistance to repeated shock when tempered at 300–350° C., but high durability at 450–500° C. Ni–Cr steel, however, tempered at low temperature, showed the best results. The effects on notched tensile strength were similar. Quenching diagrams were determined for Mn–Cr and Mn–Cr–Mo steels, and the relations between their isothermal and continuous cooling behaviour are disussed. (20 references).

Study on the Die Block Steel. T. Sugeno and E. Funaki. (*Tetsu to Hagane*, 1951, **37**, May, 291–301). [In Japanese]. The applicability of various steels (Ni–Cr–Mo, Mn–Cr–Mo, Cr–Mn and Cr–V) for forging die blocks was tested at various temperatures on a specially designed repeated-impact machine.

Effect of Heat-Treatment on the Magnetic Properties of Cold Worked 18–8. S. Storchheim. (*Wire and Wire Prod.*, 1954, **29**, Feb., 147–150). The results of experiments are reported in which commercial 18/8 stainless steel wires, cold reduced 70%, were strand-annealed in a cracked ammonia atmosphere. Annealing temperatures up to 595° C. had no effect on the magnetic properties; at about 630° C. the remanence suddenly increased; between 650° and 760° C. both remanence and coercive force changed continuously until a non-magnetic condition was reached. Both tensile strength and electrical resistivity decreased continuously with increasing annealing temperature. Above 630° C. the wire became straight.—J. G. W.

Cold-Formed Sections for Steel Framed Buildings: Economics in Material Erection Costs. R. J. Shaw and W. S. Smith. (*Iron Coal Trades Rev.*, 1954, **168**, Mar. 12, 609–614). The authors describe the use of cold-formed sections in the construction of steel-framed buildings, and discuss their economical advantages over hot-rolled sections in similar constructions. Standard design specifications are proposed, and possible methods of constructing a single-storey shed with three 40-ft. spans are illustrated.—G. F.

The Economic Upper Limited of the Strength of Concrete and Steel in Reinforced Concrete Structures (not pre-stressed) Subjected to Bending Loads. T. Gyenco. (*Acta Techn.*, 1953, **7**, (1–2), 61–70). [In French]. This paper describes tests carried out and results obtained. The strength of a high-grade steel girder may be fully exploited provided its elastic limit is 5500 to 6000 kg./sq. cm.

Constructional Alloy Steels—Chemical Composition Limits—H-Steels Hardenability Limits. (*Amer. Iron Steel Inst. Steel Products Manual, Supplement to Sections* 10, 18, 28, and 29, Feb., 1954). This 60-page publication contains tables of the compositions of standard and tentative standard steels, boron steels, and H-steels, as well as tables and curves of maximum hardness of a large number of carbon and alloy steels.—R. A. R.

On the Properties of Rimmed, Killed, and Semi-Killed Steel. K. Kikuchi and K. Horikawa. (*Tetsu to Hagane*, 1951, **37**, June, 366–378). [In Japanese]. The properties of these three types of steel are summarized and compared under the headings of the manufacturing processes, ingot conditions, variation of chemical composition, mechanical and other properties, and uses. (17 references).—K. E. J.

The Influence of Hoisting Frequency, Construction, and Material on the Durability of Wire Ropes. K. Daeves. (*Draht, German ed.*, 1954, **5**, Feb., 45–49). Evidence, based on colliery statistics in the Ruhr and on experiments, is given to show that the durability of wire ropes measured in terms of the number of failed wires depends on hoisting frequency, construction, and whether the wire is lead or air patented. Rope life varies inversely with number of working cycles per month. For a given hoisting frequency the number of failed wires increases logarithmically with time, the rate of increase being largest with DIN (German Standard) rope construction, and lowest with a compound construction (alternation of large and small diameter wires) based on air-patented wire. The affects of construction and material are pronounced only when the hoisting frequency is high. Attention is drawn to the discovery that the endurance limit for a given stress amplitude increases with the frequency of rests.—J. G. W.

Low-Alloy Steel for Coated Water-Turbine Blades. I. R. Kryanin and G. I. Babushkina. (*Liteĭnoe Proizvodstvo*, 1954, (1), 2–5). [In Russian]. Difficulties in the production of satisfactory water turbine blades from stainless steels are outlined, and an investigation is described in which various low-alloy steels were tested with a view to their use, clad with stainless steel, for this purpose. In addition to the metallographic study of sections, specimens were tested for mechanical properties after various heat-treatments. The steel selected had the composition C, 0·22–0·18%; Si, 0·80–0·70%; Mn, 1·13–1·07%. The heat-treatments recommended for this steel are summarized.—S. K.

The Sigma Phase in Stainless and Heat-Resistant Steels and Its Practical Significance. G. Pomey. (*Mét. Constr. Mécan.*, 1954, **86,** Feb., 99–106). The nature and properties of the sigma phase are first discussed with particular reference to its occurrence in alloy steels. Factors influencing the formation of the phase and the influence which its presence has on the physical properties and resistance to corrosion are considered. Improvement of the mechanical properties of austenitic stainless steel is obtained by the presence of the sigma phase and suitable methods of heat-treatment are explained. (19 references).—B. G. B.

Manganese Steel. J. Durand. (*Arts et Manuf.*, 1954, Jan., 31–33). A short account of the preparation, properties, and uses of high manganese steel is given.—B. G. B.

Study on the High-Speed Tools. (X). H. Hotta. (*Tetsu to Hagane*, 1951, **37,** Jan., 35–39; Mar., 163–166). [In Japanese]. The effects of various quenching and tempering agents (rape oil, coconut oil, machine oil, lead bath, salt bath and air) on the hardness, microstructure, and cutting properties of several high-speed steels were investigated, and studies were also made of the effects of several brazing fluxes on the hardness, strength, and cutting properties of these steels.

Notes on Specifications of Steels for Different Applications. F. Frick. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogotá, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.78). [In Spanish]. The various principles according to which steels are classified are discussed. Definitions are given of steel, steel compositions, and steel types. Mention is made of forms of steel (bar, sheet, etc.) which are subject to national specification and the relevant national specifications are quoted in respect of some of these classes.—C. B. L.

Steel Tubes for the Chemical Industry. W. E. Smith. (*Chem. Age*, 1954, **70,** Mar. 13, 617–621). Based on the experience of Accles and Pollock, Ltd., the author discusses the general economic and technological aspects of the production of steel tubes. The applications, limitations, and corrosion resistances of austenitic, martensitic, and high-chromium steels are described, and typical steel compositions and properties are given.—L. E. W.

Durimet 20–Carpenter 20. W. A. Luce. (*Chem. Eng.*, 1953, **60,** Dec., 276–288). These alloys have the composition 29% nickel, 20% chromium, 2% min. molybdenum, 3% min. copper and 1% silicon with less than 0·07% carbon. The cast alloy is employed for pickling equipment pumps, heat exchangers, valves, etc. and the wrought alloy for pump shafts, nozzles, and process piping. Their mechanical and physical properties are described together with the resistance to attack by a number of reagents.—A. G.

The Present Position Regarding the Hot Deformation of Cast Iron. A. Wittmoser. (*Z. Metallkunde*, 1954, **45,** Mar., 127–136). The author deals with the types of cast iron most susceptible to hot working, discusses the conditions most favourable to the process, and describes the alterations in structure and other properties which result from hot working. New developments are outlined, with particular reference to the use of alloy cast irons.—L. D. H.

Some Properties of White Heart Malleable Cast Iron. I. Naito. (*Tetsu to Hagane*, 1951, **37,** June, 359–365). [In Japanese]. Results were obtained concerning the change in specific gravity on annealing, the tensile strength of the graphitized and decarburized zones, embrittlement with varying silicon contents, and growth during repeated heating and cooling.—K. E. J.

Anti-Friction Cast Iron As a Complete Substitute for Bronze in the Bearings of Various Mechanisms and Machines. (*Stanki i Instrument*, 1953, (11), 37). [In Russian]. Laboratory and works trials on the use of various cast irons in machine-tool bearings are reported and discussed. Successful results were obtained with normalized pearlitic-ferritic, pearlitic and magnesium-inoculated nodular cast irons in a variety of installations including: Bolt and nut tapping machines, eccentric presses, cleaning drums, pumps, grabs, lathes, and drills. It was found that, contrary to widespread belief, the pearlite-content of anti-friction cast iron could vary over a wide range, (35–50%); and that hardness is an adequate criterion of the anti-friction properties of malleable cast iron.—S. K.

New A.S.A. Standards for Cast-Iron Pipe. (*J. Amer. Water Works Assoc.*, 1953, **12,** Dec., 1266–1280). A Panel of the American Standards Association held a discussion at the Annual Conference on May 12, 1953, on the new standards for cast-iron which have been adopted. The following papers were presented:

Development of A21 Specifications. T. H. Wiggin. (1266–1270).

Cast-Iron Pipe Tests. J. T. Vann. (1271–1275).

Manufacturing Considerations. H. W. Stuart. (1275–1276).

Consulting Engineer's Viewpoint. L. R. Howson. (1276–1278).

Manager's Appraisal. W. R. La Due. (1278–1280).

On the Properties of Cast Iron Melted by an Electric Furnace. (II). T. Kinoshita, A. Odawara, and K. Kinoshita. (*Tetsu to Hagane*, 1951, **37,** Aug., 461–465). [In Japanese]. Compared with cupola iron, the FeO and hydrogen contents are higher, leading to abnormal graphite distribution, lower impact values, brittleness, and shrinkage cavities.—K. E. J.

METALLOGRAPHY

The Micro-Mechanism of Fracture in Ferrite. W. H. Bruckner. (*Acta Met.*, 1954, **2,** Jan., 168–169). [In English]. The author records metallographic evidence to support his view that mechanical twinning may be directly responsible for the onset of cleavage.—A. D. H.

Cold Rolled and Primary Recrystallization Textures in Cold-Rolled Single Crystals of Silicon Iron. O. G. Dunn. (*Acta Met.*, 1954, **2,** Mar., 173–183). [In English]. Quantitative pole figures for the cold-rolled and primary recrystallization textures are presented and discussed. Each primary recrystallization texture is shown to consist of several preferred orientations with one component predominant. It is concluded that large primaries from a minor component of the primary structure grow to become secondaries of the same preferred orientation provided that they are large enough to grow in competition with other primaries and do not come from a component which by itself, or with a twin component, represents too large a portion of the structure. The results agree better with Burger's theory than with other current theories.—A. D. H.

Residual Lattice Strains in Iron Single Crystals. J. H. Auld and G. B. Greenough. (*Acta Met.*, 1954, **2,** Mar., 209–213). [In English]. X-ray diffraction measurements of the interplanar spacing of single crystals of iron after plastic deformation were made and the residual lattice strain shown to be negligible. It is concluded that the residual lattice strains previously found in polycrystalline metals are due to an intergranular stress system rather than to stresses associated with trapped dislocations.—A. D. H.

Spontaneous Deformation of Austenite During Martensitic Transformations. B. Edmondson and T. Ko. (*Acta Met.*, 1954, **2,** Mar., 235–241). [In English]. By metallographic examination, plastic deformation is shown to take place in austenite during the martensitic transformation in a 34/66 Ni–Fe alloy. The permanent distortion remaining after all the martensite has reverted to austenite has an important effect on the subsequent formation of martensite. Slip lines in austenite have been observed in 18%-Ni, 1%-C and 5%-Ni, 1·5%-C steels. The effects of spontaneous deformation on the kinetics of the martensitic transformation are discussed.

The Relation of the Disordering of a Superlattice to the Melting of a Disordered Alloy. R. A. Oriani. (*Acta Met.*, 1954, **2,** Mar., 343–344). [In English]. An empirical correlation between the critical temperature of disordering of a superlattice in an alloy and the solidus temperature of the disordered alloy of the same composition is pointed out.

Faulting in Austenite. H. M. Otte. (*Acta Met.*, 1954, **2,** Mar., 349–352). [In English]. Drastic quenching of certain Cr steels causes markings in the austenite which delineate

the {111} planes. These are detectable by X-ray diffraction methods and are interpreted in terms of stacking faults.

Magnetic and Thermomagnetic Analysis. G. Guiot-Guillain. (*Chim. Analy.*, 1954, **36**, Jan., 9–17). The principles of magnetic and thermomagnetic measurements are outlined and the applications of the techniques are reviewed. The thermomagnetic method has been used to follow the transformations of Fe–C–N alloys, to study the diffusion of two metals arranged as a laminated specimen, and to investigate the heterogeneity of alloys.—B. C. W.

Isothermal Transformations in Cast Iron. J. Ings. (*Australian Inst. Metals: Australasian Eng.*, 1953, Nov. 7, 62–67). The compositions and structures of the various types of cast iron are briefly reviewed and the isothermal transformations from the austenitic condition are discussed with reference to the TTT curves. The effects of constituent and alloying elements on these transformations are described, and the practical uses of isothermal data in the production of irons having very different properties are dealt with. (10 references).—P. M. C.

On the Stabilization at Room Temperature of Quenched High-Speed Steels. M. Okamoto and M. Nagakura. (*Tetsu to Hagane*, 1951, **37**, Sept., 468–471). [In Japanese]. The longer the holding time at room temperature the less is the amount of Ms′ transformation on subzero cooling, and the transformation temperature is lowered. By cooling to −150° C., the secondary Ar″ point occurs at − 25° C., and further tempering at 600° C. brings the tertiary Ar″ transformation point above room temperature.—K. E. J.

Occurrence of Silicon Carbide in the Fe–C–Si System. J. C. Fulton and J. Chipman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**; *J .Met.*, 1954, **6**, Mar., 356–357). A study has been made of alloys of the Fe–C–Si system containing about 20–23% Si, and the identity of a second solid phase, more stable than graphite with respect to the solution, has been established as β-SiC.—G. F.

Chromium–Oxygen Equilibrium in Liquid Iron. E. T. Turkdogan. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 278–283). [This issue].

Presidential Address. L. B. Pfeil. (*Bull. Inst. Metallurgists*, 1953, **4**, Aug., 9–15). The author reviews some of the outstanding metallurgical developments during the past 30 years. The constitutional study of alloy systems, the increasing understanding and application of precipitation hardening, and the expanding knowledge of the decomposition of austenite and the mechanism of martensitic hardening are referred to. There have been striking advances in the methods of production, treatment, and alloying of cast iron resulting in the austenitic corrosion-resisting non-magnetic, and nodular graphite types. The stainless steels have been greatly developed, particularly the precipitation-hardening grades containing copper, aluminium, and titanium. In recent years powder metallurgy and precision casting have passed from the experimental to the commercial stage.—L. E. W.

Study of the Hot Work Tool Steels (II). M. Tagaya, A. Adachi, S. Matsumoto, and K. Tuji. (*Tetsu to Hagane*, 1951, **37**, Feb., 97–102). [In Japanese]. The isothermal transformation of a standard tool steel was determined between 810° and 400° C. After quenching from 1200° C., the austenite transforms rapidly at 775° C., and very slowly between 600° and 460° C. The supercooled austenite gives way to an acicular martensitic structure just below 400° C.—K. E. J.

Is Ms Temperature Influenced by Cooling Rate? C. L. M. Cottrell. (*Brit. Welding, J.*, 1954, **1**, Apr., 160). A rapid action dilatometer was used to examine the transformation characteristics of a 3½%-Ni–Cr–Mo steel during continuous cooling. The results show conclusively that for the steel in question the Ms temperature (temperature at which martensite begins to form) is influenced by the cooling rate.—U. E.

Theoretical Analysis of Diffusion of Solutes During the Solidification of Alloys. C. Wagner. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**; *J. Met.*, 1954, **6**, Feb. Section 1, 154–160). When an alloy solidifies, the degree of segregation depends on factors including the partition ratio of alloying element between liquid and solid phases, solidification ratio, and convection. The author has made theoretical calculations for a liquid with no convection, with natural convection, and with forced convection. The calculations apply directly only to low solute concentrations.—G. F.

On a Martensitic Transformation of the Phase FeO. R. Collongues. (*Acta Crystallographica*, 1954, **7**, Feb. 10, 213). [In French]. A brief note draws attention to a low temperature martensite transformation of high oxygen solid solutions of FeO.—B. C. W.

On the Boundary Parameters of the Phase FeO. J. Bénard. (*Acta Crystallographica*, 1954, **7**, Feb. 10, 214). [In French]. Recent determinations of the lattice parameters of FeO in the presence of excess iron or excess Fe_3O_4, are shown to be in close agreement with the values previously obtained by the author.—B. C. W.

On the Question of the Mechanism of the Decomposition of Supersaturated Solid Solutions in Alloys. Yu. A. Bagaryatskii. (*Zhurnal Tekhnicheskoi Fiziki*, 1951, **21**, (12), 1497–1503; *Fulmer Research Inst. Ltd. Translation No.* 45). Based on published literature, a theory of the mechanism of supersaturated solid solution decomposition is developed with special reference to the martensite in steels.—S. K.

Present State of the Metallurgy of Austenitic Alloys, Particularly the 18/8 Steels. Part III—Martensitic Changes in High Alloy Austenitic Steels. P. Bastien and J. Dedieu. (*Metaux-Corrosion-Indust.*, 1954, **29**, Feb., 49–56). Information available concerning martensitic changes in high-alloy steels is reviewed. The graphical representation of martensitic transformations is discussed and the effect of plastic deformation and applied stresses on the transformation is considered. Recent work carried out on the isothermal formation of martensite at very low temperatures is also discussed. (18 references).—B. G. B.

The Diffusion of Silver into Iron–Palladium Alloys and the Internal Adsorption of Palladium in Iron. V. I. Arkharov and B. A. Yunikov. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94**, (6), 1057–1060). [In Russian]. The diffusion of silver into Fe–Pd alloys was investigated. Palladium is internally adsorbed in its iron alloys at palladium concentrations below 10% ; at higher concentrations it loses its positive adsorption activity and is distributed in the polycrystalline alloy without any noticeable increase of concentration at the intercrystalline boundaries. The diffusion of silver in Fe–Pd alloys increases with increasing palladium concentration above 10%, and is also high at concentrations below 4%.

The Influence of the Velocity of Heating on the Position of the Temperature Range of the Pearlite–Austenite Transformation. A. P. Gulyaev and V. M. Zalkin. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (2), 216–221). [In Russian]. The influence of the speed of heating on the position of the Ac_1 point was studied. The chemical composition and the initial structure of specimens are given. Heating was effected by passing a current through the specimen and the temperature was measured using a photoelectric pyrometer and an oscillograph. The velocity of heating was varied from 10° to 1000° C./sec. Experimental data indicated that the dependence of the Ac_1 point on heating velocity can be expressed by $\Delta T = a + 25 \times \log V$, where ΔT = displacement of Ac_1 point from the equilibrium temperature, taken as 720° C., V = heating velocity in degrees/sec., and a = a coefficient depending on the degree of dispersion of the initial structure.—V. G.

Transformation of Cr–Mo Steels During Welding. W. R. Apblett, jun., R. P. Dunphy, and W. S. Pellini. (*Welding J.*, 1954, **33**, Jan., 57s–64s). The continuous cooling transformations of two chromium–molybdenum steels (one 1·25% Cr, 0·5% Mo, and the other 2·25% Cr, 1·0% Mo), have been determined for austenitizing and cooling conditions. It was found that when preheating these steels to temperatures as high as 600° F. a relatively minor decrease in the maximum hardness occurred.—U. E.

On the Problem of Analysing Thermal Curves for the Rapid Heating of Steel. A. P. Gulyaev and V. M. Zalkin. (*Zhurnal Tekhnicheskoi Fiziki*, 1954, **24**, (2), 222–226). [In Russian]. The interpretation of thermal curves obtained at high heating rates for steel specimens is discussed. The conclusions are supported by metallographic studies of the pearlite–austenite transformation at high heating rates (150° C./sec.).—V. G.

Application to Iron of Borelius' Theory of Structure Relationship between the Solid and Liquid States. O. Krisement and F. Wever. (*Appl. Sci. Res.*, 1954, **4A**, (4), 249–265). [In German]. A theory developed by Borelius, concerning the continuity during transition of a metal from the solid to the liquid state, has been applied to iron. Details of the investigation are described and discussed. It is probable that Borelius's theory applies to the transition from α-iron to liquid iron but not to the transition of γ-iron to the liquid state.—E. C.

Kinetics of the Austenite–Martensite Transformation at Low Temperatures. G. V. Kudryumov and O. P. Maksimova. (*Doklady Akademii Nauk S.S.S.R.*, 1948, **61**, (1), 83–86). Kinetics of the austenite–martensite transformation at sub-zero temperatures were studied using a magnetometric method. The transformation rates at different temperatures were determined for steel containing 6% Mn. From the results obtained, the activation energy of the formation of martensite nuclei was calculated as being equal to 1600 cal./mol.—V. G.

Investigations of the Transformation Tendency and the Hardenability of Steels. E. Greulich. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 137–152). Investigation of the isothermal austenite transformation of stainless chromium steels (12–14% Cr) has shown that the minimum value of the 50% transformation time is a criterion of the transformation tendency and the hardenability of the steels. The natural logarithm of this value allows a division of steels according to their hardenability, rising from the value of one for unalloyed steels to 5–8 for stainless steels. The conditions for carrying out a recommended hardenability test with disc specimens were derived from isothermal transformation diagrams of unalloyed and simple alloy steels.—J. P.

CORROSION

Fundamental Principles of Corrosion. E. Lange. (*Schweiz. Arch. Wiss. Techn.*, 1952, **18**, Dec., 395–404). The fundamental principles of corrosion regarded as an electrochemical phenomenon are developed and illustrated by examples which include both dry corrosion (metal/metal and oxide/oxygen) and wet corrosion (metal/metal compound/aqueous solution of corrosive substance). The paper is based largely on recent German work.—H. R. M.

The Acid Dew-point. J. R. Rylands, J. R. Jenkinson. (*J. Inst. Fuel*, 1954, **27**, June, 299–318: *Eng. Boiler House Rev.*, 1954, **69**, Apr., 104–111). The paper is concerned with the potency of flue gases in regard to their corrosive effects on metal parts. The electrical dew-point meter is considered, and it is concluded that this type of instrument is unreliable and misleading. Some experiments on the measurement of acid deposition by analytical methods are described. It was found that the acid dew point temperature varies only slightly with wide variations of SO_3 content in combustion gases. The mechanism of corrosion by sulphurous gases and possible means of suppression are considered. Hydrochloric acid may cause serious corrosion below the water dew-point.—D. L. C. P.

Effect of Surface Condition on the Rate of Corrosion of Iron in the Ground. T. Markovic. (*Werkstoffe u. Korrosion*, 1954, **5**, Mar., 81–83). Experimental results suggest that the behaviour of electrolytic cells formed by smooth iron, rough iron, and a soil in different degrees of saturation with water is characteristic of the soil and may be used to predict its corrosiveness.—J. C. H.

Corrosion of Buried Copper and Ferrous Strip in Natural and Salted Soils. (*Brit. Elect. Allied Ind. Res. Assoc., Rep., No.* V/T 110, 1950). An investigation to determine the relative corrodibility in different soils of various metals such as are, or might be, used for earth electrodes, and the relative corrosivity of the soils in relation to such metals, is described. The effect of salt treatment is discussed and a comparison with other soil corrosion studies is made. The tests covered exposures up to twelve years and, as regards ferrous strip, it was found that: (1) In natural soils unprotected specimens lost up to 2% per year and more in salted soils; (2) in general, mild steel is given considerable and apparently permanent protection by galvanizing; (3) only in a few cases was there any indication that corrosion was accelerating; and (4) the effects of salting appear to persist over many years in most cases.—L. E. W.

The Fight Against the Corrosion of Iron—Protection by Paint. A. Marty. (*Mét. Constr. Mécan.*, 1954, **86**, Mar., 235–244). The problem of protecting iron against corrosion is considered. Methods used to prepare the surface before painting are discussed; these include sandblasting, pickling, degreasing, and phosphatizing. The properties and performance of a number of different paints including oil, oil-bound resinous, bitumastic, and cellulose types are reviewed. The selection of paints for particular circumstances and the application of a protective coating of paint are discussed.

Note on Cathodic Protection. W. Thury. (*Werkstoffe u. Korrosion*, 1954, **5**, Mar., 84–87). From the results of experiments on the cathodic protection of steel and aluminium in 5% H_2SO_4 and other solutions, the author calculates the consumption of anodic metal, when sacrificial anodes are used, or of electrical energy, when a protective current is applied. These figures form a basis for comparing the costs of the methods.—J. C. H.

Causes of Corrosion in Deep Well Water Pumps in Israel. D. Spector. (*Corrosion*, 1954, **10**, Apr., 122–123).

The Break-Through Potential of Passive Iron–Chromium Alloys in Sulphate Solutions. G. Masing, T. Heumann, and H. Jesper. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 169–180). While passive pure iron at the break-through potential in sulphate solutions liberates only oxygen, addition of chromium to the iron changes its behaviour so that the alloy dissolves at the same time as oxygen is evolved. The greater the chromium content, the more the alloy goes into solution, until, with high chromium, no oxygen is evolved at all; the chromium dissolves in the hexavalent state. With medium chromium contents and particularly in acid solution, and at higher temperatures, the current density decreases again after passing the break-through potential, the potential jumps to the oxygen potential, and solution of alloy and evolution of oxygen then take place. This phenomenon is named secondary passivation. The explanations of these observations have as yet only a hypothetical character.—J. P.

The Corrosion of Iron in Contact with an Aqueous Solution of an Electrolyte Containing Sodium Nitride Additions and a Liquid Fuel. I. V. Krotov and V. V. Klubova. (*Zhurnal Prikladnoi Khimii*, 1954, **27**, (2), 201–206). [In Russian]. Three series of experiments in which the corrosion of iron in contact with an electrolyte (distilled water, 3% NaCl solution, synthetic sea water with additions of sodium nitrite) and a liquid fuel (aviation spirit and petroleum) were investigated. It was found that the additions of sodium nitrite in concentrations from 0·1 to 0·5 *N* do not completely inhibit the corrosion process.—V. G.

Dependence of the Rate of Corrosion of Iron on the *p*H of the Salt (KCl) solution. L. K. Lepin and A. Ya. Vaivade. (*Zhurnal Fizicheskoĭ Khimii*, 1954, **28**, (3), 435–439). [In Russian]. An investigation of the rate of corrosion of iron under static conditions in KCl solutions of initial *p*H values 3·0–9·0 with an atmosphere of air is described. Experiments were made with low ratios between volume of liquid and the surface of the specimen. The rate was found to depend on the rapidly established stationary value of the *p*H. For initial *p*H values of 4–9, this value was 6·8–6·9, corresponding to the region of ferric-oxide stability. For initial *p*H values of 3, the value was about 5·7, and this is related to changes in composition and properties of oxidation products. Decreasing stationary *p*H values lead to enhanced corrosion rates.—S. K.

Investigation of Some Liquid Lubricants Preventing Corrosion of Steel Parts During Their Manufacture and Storage. V. V. Skorchelletti and V. E. Piskorskii. (*Zhurnal Prikladnoi Khimii*, 1954, **27**, (3), 314–318). [In Russian]. Among many methods of preventing the corrosion of machined steel parts during manufacture and storage, some petroleum oils are used. These, however, are not satisfactory due to their oxygen solubility and the penetration through the oil films of steam and other corrosive gases. The use of an oil suspension of chromate, dichromate, and other powders was therefore investigated. The best results were obtained with an oil suspension of potassium chromate powder. From the salts of high molecular organic acids the best protective properties were shown by the monatanone barium soap.—V. G.

High-Temperature Oxidation of Iron and Steel. N. P. Zhuk and B. V. Linchevskiĭ. (*Zhurnal Fizicheskoĭ Khimii*, 1954, **28**, (3), 440–452). [In Russian]. The continuous weighing method was used in the investigation described for the elucidation of the oxidation kinetics of iron and four steels in air in the temperature range 400–1100° C. Changes in the temperature dependence of the oxidation rate were observed at 480–580° C., 730–770° and 850–880° C. Activation-energy calculations showed the changes 7000 to 16,000 cal., 16,000 to 40,000 cal. and 40,000 to 25,000 cal., associated with various structural transformations. With additional data from the literature, the oxidation process has been established for the whole 20–1100° C. range. In the range 400–1100° C., the process follows a parabolic law, the rate-controlling factor being reaction-diffusion in the metal-scale contact region. Graphs useful for choosing the type of metal for a particular temperature are presented.—S. K.

Investigation of High-Temperature Oxidation Processes of Iron Powder. P. D. Dankov and N. K. Andrushchenko. (*Zhurnal Fizicheskoĭ Khimii*, 1954, **28**, (3), 519–524). [In Russian]. The kinetics of the oxidation of specimens made by compressing mechanically powdered Armco iron at 200, 400, 600, 800, and 1000° C. were studied. Phase changes similar to those in massive iron were observed, and at about 800° C. the rates of oxidation were similar. Consideration of the mechanism of the process suggested that residual nitrogen in the inter-particle pores is an important factor.

Robert Mallet—Pioneer Corrosion Engineer. W. Lynes. (*Corrosion*, 1954, **10**, Feb., 59–62). An appraisal of the considerable knowledge of corrosion shown by Robert Mallet in 1838–42 is followed by a brief review of progress in this subject since then.—J. F. S.

ANALYSIS

Application of the A.R.L. Quantometer to Production Control in a Steel Mill. H. C. Brown. (*Trans. Amer. Inst. Min. Met. Eng.*, 1954, **200**: *J. Met.*, 1954, **6**, Mar., 349–352). The author discusses the use of the A.R.L. production control quantometer at the Armco Steel Corp. for the production control of all types of stainless steel and for the rapid analysis of final tests from stainless, silicon, and plain carbon steels. Substantial savings in laboratory manpower and time have been made, and the accuracy of quantometric analysis compares favourably with that of routine chemical methods.

Apparatus for Automatic Control of Cathode Potential in Electro-Analysis. J. F. Palmer and A. I. Vogel. (*Analyst*, 1953, **78**, July, 428–439). A D.C. output unit working from A.C. mains for low voltage current, a valve voltmeter, and a high-tension power-pack are assembled with other equipment to provide automatic potential control to ± 1 millivolt. The units mentioned can be used independently for other laboratory applications.—J. O. L.

An Application of High Voltage A.C. Arc Source to the Spectrographic Analysis of Steels. T. Nakajima, T. Mitsuhashi, and Y. Shiraishi. (*J. Mech. Lab.*, 1953, **7**, Sept., 197–201). [In Japanese]. An arc source of 4,400 V. 2 amp. to 2200 V. 4 amp. A.C. was designed and manufactured. Quantitative tests of Mn, Ti, Si, Ni, Cr, and analyses in steels established a reproductibility of 3 to 8%, negligible background, and small sample loss on account of the lower electrode temperature.

Automatic Time Switch for Spectrography. G. Reiniger and G. Balz. (*Metall*, 1954, **8**, Feb., 98–101). A new electronic timing device, manufactured by Wandel and Goltermann, Reutlingen, is described. The novel features comprise electronic control of time pulses, automatic repeat mechanism, simple means of multiplying spark and exposure times, built, in rectifier so that the apparatus can be plugged directly into the 220–V. A.C. mains. The design and method of operation are described.—J. G. W.

A Highly Selective Procedure for the Spectrophotometric Determination of Aluminium with 8-Hydroxyquinoline and Its Application to the Determination of Aluminium in Iron and Steel. A. Claassen, L. Bastings, and J. Visser. (*Anal. Chim. Acta.*, 1954, **10**, Apr., 373–385). Aluminium hydroxyquinolate can be quantitatively extracted by chloroform from an ammoniacal solution containing hydroxyquinoline, complexone, and cyanide. Applications are given for the determination of trace and higher amounts of aluminium in steels and non-ferrous alloys. (12 references).—L. E. W.

Rapid Determination of Manganese in Iron and Steel by Vanadyl Sulphate. I. Tsubaki. (*Tetsu to Hagane*, 1951, **37**, Mar., 167–168). [In Japanese]. Details are given of a method using vanadyl sulphate, which gives a sharper and more accurate titration. than the arsenious method ; the time required is only 10 min.—K. E. J.

On the Rapid Determination of Mn in Iron and Steel by $(NH_4)_2$ S_2O_8–As_2O_3 Method (II). K. Hosoda and K. Kawamura. (*Tetsu to Hagane*, 1951, **37**, Jan., 30–34). [In Japanese]. Difficulties due to variation in the manganese titre of the same AsIOI solution with the manganese content of the steels used for standardization led to the adoption of adding KCl or NaCl before titration, to eliminate the error.—K. E. J.

A Polarographic Method of Determining Lead in Iron and Steel Products. Ch. Gandon. (*Chim. Analy.*, 1953, **35**, Oct., 251–252). A polarographic method is described for determining lead in steels, ferro manganese, or pyrites. The material is dissolved in hydrochloric acid and the solution is treated with hydroxylamine hydrochloride, the *p*H being adjusted to 3 with ammonia. The copper content of part of the solution is determined polarographically and the Cu/Fe ratio of the remaining portion adjusted to be greater than 0·005. After addition of potassium thiocyanate and filtering, the height of the polarographic curves is measured before and after the addition of a known volume of a standard lead solution. From the two readings the lead content of the original solution may be obtained.—B. C. W.

A Contribution to the Determination of Lead in Steel. H. A. Nicolas. (*Chim. Analy.*, 1954, **36**, Jan., 8). A rapid method is given for the determination of lead in steel. The sample is dissolved in hydrolchoric acid, the solution filtered and, after the addition of hydroxylamine hydrochloride, electrolysed using a rotating anode.—B. C. W.

Amperometric Titration of Nickel in Steels with Diphenylglyoxime. K. Szmidt. (*Prace Instytutow Mechaniki*, 1953, **3**, (8), 1–5). [In Polish]. A polarographic method of determining nickel in steels using α–diphenylglyoxime was tested. For steels in which the nickel content was above 0·25%, the results obtained were within 3·3% of those obtained by the usual gravimetric method. The procedure is described.—V. G.

Analytical Chemistry of W and Mo (with Particular Reference to Steel and Allied Materials. B. Bagshawe. (*Chem. Age*, 1954, **70**, Jan. 23, 267–274 ; Jan. 30, 309–312). Methods of separating tungsten and molybdenum before determining them gravimetrically are discussed and the use of dithiol and thiocyanate for determining them colorimetrically is described.

Elimination of the Effect of Sulphur in the Direct Combustion-Gasometric Method of Determining Carbon in High-Sulphur Iron and Steel. T. Ikegami and K. Suematsu. (*Tetsu to Hagane*, 1951, **37**, Sept., 485–490). [In Japanese]. The best methods of eliminating the interfering oxides of sulphur are to use $KMnO_4$, CrO_3, or H_2O_2 in the absorption tube.—K. E. J.

A Semi-Micro Wet Combustion Method for the Determination of Carbon. E. E. Archer. (*Analyst*, 1954, **79**, Jan., 30–33). This method depends upon decomposition of the sample for analysis by treatment with an oxidizing solution, further oxidation of the evolved gases by a heated silver spiral and absorption of carbon dioxide in barium hydroxide solution. Excess hydroxide is neutralized and the precipitated carbonate titrated, using suitable indicators and correction factors.—J. O. L.

Conductimetric Determination of Carbon in Metals. J. E. Still, L. A. Dauncey, and R. C. Chirnside. (*Analyst*, 1954, **79**, Jan., 4–17). Following the normal technique of combustion in oxygen, carbon dioxide is absorbed in sodium or barium hydroxide solution and evaluated by the change in electrical conductivity of the solution. Important features of the apparatus are an improved loading device with an inspection window and a conductivity cell constructed of plastic, designed to ensure complete absorption, forming one arm of a Wheatstone bridge comparator. Satisfactory results have been obtained on 1-g. samples of steel or cast iron with carbon between 0·03 and 3%, also on other metallic samples weighing 0·1 to 3 g. containing 8 to 0·01% of carbon. Barium hydroxide is used for precise determinations at low carbon levels.

Determination of Carbon and Hydrogen by Calorimeter Bomb. R. K. S. Mehta. (*J. Sci. Indust. Res.*, 1954, **13**, Mar., 195–203). A method for the determination of carbon and hydrogen in fuel using the calorimeter bomb, especially suitable for the analysis of volatile fuels, is described ; the interfering effects of various constituents are allowed for.—J. O. L.

The Determination of Silicon in Tungsten and Titanium Metal Powders, Carbide Sintering Alloys, Tungstic Oxide and Tungstates. B. Bagshawe and R. J. Truman. (*Analyst*, 1954, **79**, Jan., 17–23). The sample is calcined to oxide, fused with sodium carbonate, extracted in such a way as to prevent loss of silicic acid by hydrolysis, and treated by an appropriate process to convert silicon via molybdisilicic acid to molybdenum blue. The conditions of solution and colour development need to be adjusted according to the composition of the material for analysis.—J. O. L.

The Determination of Hydrogen in Mild Steel Arc Welds—Method of Presenting the Results. A. Roux. (*Rev. Mét.*, 1954, **51**, Mar., 192–202). Tests are described aimed at establishing a sampling technique for metal deposited by arc welding, in order to determine the hydrogen content. The results show that specimen dimensions are not critical but the rate of movement of the electrodes should be constant. The

volume of hydrogen must be related to the total weight of metal melted, including any parent metal melted during welding.—A. G.

The Mirco-Determination of Traces of Gaseous Elements in Metals by the Vacuum Fusion Method. J. N. Gregory, D. Mapper, and J. A. Woodward. (*Analyst*, 1953, **78**, July, 414–427). Experimental work and details of the apparatus are fully described. The method has been employed for oxygen, hydrogen, and nitrogen in steel and uranium with an accuracy better than ±10 p.p.m. on 50–200 mg. samples, but determinations on zirconium were unsatisfactory.—J. O. L.

Diffusion of Hydrogen in Mild Steel. A. Demarez, A. G. Hock, and F. A. Meunier. (*Acta Met.*, 1954, **2**, Mar., 214–223). [In English]. Apparatus is described for the vacuum extraction of hydrogen from steel. It can be used for the rapid determination of hydrogen and of the diffusion coefficient. The diffusion of hydrogen from a finite cylinder is considered and compared with experimental data for 650° C. The hypothesis that hydrogen in steel exists in two forms is not supported by the results which are in reasonable agreement with the normal laws of diffusion.—A. D. H.

The Analysis of Alloy Constituents of Iron. Part II—Determination of Tungsten and Titanium. W. Meier. (*Schweiz. Arch. Wiss. Techn.*, 1953, **19**, Aug., 245–249). Both tungsten and titanium are determined by absorptiometric methods. The yellow complex of tungsten with thiocyanate in strong HCl is used after reduction with stannous chloride. The determination of titanium is made with the yellow titanium peroxysulphate after separation from interfering elements by the use of a mercury cathode, followed by precipitation with potassium hydroxide.—H. R. M.

Improvements in the Absorptiometric Determination of Tungsten. Methods of Analysis Committee. (*J. Iron Steel Inst.*, 1954, **178**, Nov., 267–269). [This issue].

Oxygen Determination in Solid Steel by the Gotta Aluminium-Diffusion Method. J. Massinon, N. Stoll, and M. Urbain. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 107–114). A co-operative study is reported of the method of estimating total oxygen in solid steel by heating samples in a mixture of alumina and aluminium powder and then analysing the steel for alumina. The experimental procedure and precautions to be taken are fully described and the results are compared with others obtained by vacuum-fusion. Whilst the method is a useful one, in that it does not require any special equipment and is apparently reproducible, it is not at all clear that the results are accurate.—J. P.

The Residual Oxygen Content of Cupola-Melted Gray Cast Iron. E. A. Loria and H. W. Lownie, jun. (*Trans. Amer. Soc. Metals*, 1954, **46**, 409–417). A critical discussion is given, of knowledge and data on the presence and measurement of oxygen in cast iron.—D. L. C. P.

Photometric Determination of Nitrogen in Steels. C. Artero Soteras. (*Inst. Hierro Acero*, 1954, **7**, Jan.-Mar., 44–47). [In Spanish]. This method is that of Newell (*J. Iron Steel Inst.*, 1945, **152**, 333P) adapted to the Pulfrich photocolorimeter. No previous distillation is required. Experimental details are given. The method is very rapid and simple.—C. B. L.

Determination of Sulphur by Gaseous Evolution in Steels, Iron, and Cast Irons. B. E. Jaboulay. (*Chim. Analy.*, 1954, **36**, May, 130–131). For 10-g. samples the action of iodine on the solutions of zinc acetate (25 g. in 1000 c.c.) employed may be neglected. With the more dilute solutions of iodine and hyposulphite used on 3-g. samples, this source of error must be allowed for by adjusting the correction coefficient.

Determination of Sulphur in Ores and Slags. R. Boulin, R. Desguin, and E. Jaudon. (*Chim. Analy.*, 1954, **36**, May, 123–125). The authors have applied the method of Fincham and Richardson, in which the formation of SO_3 is avoided by using CO_2 as a combusting agent, to basic-Bessemer slags and iron ores. Some results are given and a considerable saving in time is reported.—A. G.

Separation of Oxide Inclusions in Steels and Cast Irons. S. Mischonsniky, Ch. Dubois, and P. Bastien. (*Rev. Mét.*, 1954, **51**, Apr., 233–253). The principal methods for the separation of inclusions are reviewed and a description is given of the authors' technique combining aqueous iodine extraction with a preliminary electrolytic separation. Good agreement was observed with results of vacuum-fusion in a modified apparatus permitting analysis of the gas in an Orsat micro-instrument. The residue method is compared with these of vacuum-fusion and aluminium reduction, and applications to industrial problems such as forging brittleness, the performance of ingot moulds and the oxygen content of sintered carbides are discussed.—A. G.

Electrochemical Processes during Electrolytic Isolation of Residues from Steels by Alternating Current. W. Koch, I. Ramsauer, and M. v. Stackelberg. (*Arch. Eisenhüttenwesen*, 1954, **25**, Mar.-Apr., 93–106). Since certain steels, particularly those containing chromium, tend to go passive during anodic dissolution, electrolysis might be conducted with square-pulsed alternating current, the hydrogen produced during the cathodic periods serving to activate the steel for the subsequent anodic periods. The anodic current efficiencies for metal dissolution are, however, low and this is due to anodic dissolution of hydrogen absorbed into the metal during cathodic discharge. The changes of anode and cathode potential with time during a single current cycle and with progressive electrolysis have been studied on samples of iron and alloy steels of different composition, grain size, and degree of cold work, and these have been related to anodic dissolution efficiencies. The effects of changes of composition of the electrolyte have also been examined. It is now possible, by applying the technique, to determine the best procedures for isolating residues from different steels.—J. P.

Direct Titration of Zinc and Cadmium in Cyanide Solutions. J. P. Leftin. (*Metal Finishing*, 1954, **52**, Apr., 74–75).

Analysis of Electroplating Solutions. I—Estimation of Boric Acid in the Presence of Nickel Salts. M. R. Verma and K. C. Agrawal. (*Electroplating*, 1954, **7**, May, 171–172).

ECONOMICS AND STATISTICS

World Steel Production and Consumption. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1953, **28**, Feb., 1–3). Statistics on world steel production with an estimate of the apparent consumption of steel per head in different countries are presented and discussed.—R. A. R.

Steel in the Commonwealth. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1953, **28**, June, 5–17). Resource of coal, iron ore, manganese ore, and scrap in the countries of the Commonwealth are reviewed, statistics of steel production, imports and exports are presented, and the plans for increasing outputs are indicated.—R. A. R.

The Export Trade of the German Iron and Steel Industry and the Development of the Steel Market of the European Coal and Steel Community in 1953. W. Schwede. (*Stahl u. Eisen*, 1954, **74**, May 6, 601–603). The decreased production and nett export of steel by Western Germany in 1953 as compared with 1952 are discussed and the reasons therefore analysed. The production, export and import of steel by France, Belgium-Luxembourg, Holland, and Italy are compared and the changes as compared with 1952 are related to present economic conditions and to the activities of the High Authority.—J. P.

Statistics and Documentation for Various Countries. (*Annales des Mines*, 1954, **143**, (2–3), 1–308). The whole of this issue is devoted to tables and notes giving information on production and other commercial aspects of coal, crude oils, natural gas, ores, and ferrous and non-ferrous metals. One index includes the countries, materials and processes. Literature references are also given in many cases.—R. A. R.

Demand for Steel. A. Jones. (*Financial Times Annual Review of British Industry*, 1954, p. 8). At the present time the British steel industry is working at full capacity and the demand is likely to increase; on the other hand the American and Continental steel industries are working at below 70% and a little over 80% of nominal capacity respectively. The causes of this are examined. The rise in capital cost per ingot ton of a new integrated plant and its effects are considered.

The Spanish Iron and Steel Industry. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1953, **28**, Jan., 5–19). The difficulties confronting any expansion of the Spanish iron and steel industry are outlined. The resources, nature, and mining of the iron ores of Spain and of Spanish Morocco are reviewed with emphasis on the prospects of utilizing the large reserves of low-grade high-silica ores. Details of existing plants at the principal Spanish works and of the new integrated plant to be erected at Avilés are given.—R. A. R.

The French Steel Development Plan. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1953, **28**, Feb., 5–11). Progress made during 1947–51 in the Monnet Plan for developing the French iron and steel industry is reported.—R. A. R.

The First Steel Development Plan. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1952, **27**, Nov., 1–9). An outline is presented of the first post-war Development Plan for the iron and steel industry of Great Britain, the general objective of which was to modernize and increase steel capacity to 16 million tons a year.—R. A. R.

The Luxemburg Iron and Steel Industry. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1952, **27**, Aug., 1–15). The development and present position of the iron and steel industry of Luxemburg are discussed and data are presented on consumption of raw materials, production, costs, employment, and average earnings.—R. A. R.

Steel Supplies and Industrial Production. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1952, **27**, July, 1–6). The significance of iron and steel production in the economy of Great Britain is discussed, and the position of the iron and steel industry with regard to labour, raw materials, and demand for its products is considered.—R. A. R.

The Italian Iron and Steel Industry. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1952, **27**, Apr., 1–10). The organization and development of the iron and steel industry in Italy is described and data on the capacities and outputs of the principal producers. A methane gas grid has already been constructed in northern Italy and the steelmaking centres are using it more and more in place of imported solid fuel. Particulars of the new Cornigliano plant at Genoa are given.

Steel Developments in Rumania. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1952, **27**, Feb., 3–14). The importance of the iron and steel industry of Rumania is discussed and data on iron ore reserves, capacity of plants, and production, are presented.—R. A. R.

MISCELLANEOUS

The Impact of Research on the Industrial Developement of the West. A. M. Zarem. (*Amer. Iron Steel Inst., Regional Tech. Meetings*, 1953, 217–230).

Physics and the Iron and Steel Industry. P. Bastien. (*Genie Civil*, 1954, **131**, Apr. 15, 146–148). The role of physics in providing new methods of controlling production, developing new techniques of laboratory investigation and in the creation of the theory of the physics of metals is discussed.

Some Aspects of Labour Problems in the Iron and Steel Industry. (*United Nations Economic Commission for Latin America Conf. on the Iron and Steel Industry in Latin America*, Bogotá, Colombia, Oct. 13–Nov. 5, 1952, *Paper* L.81. [In English].

Accident Prevention in the Iron Steel Industry. J. Wadsworth. (*Iron Coal Trades Rev.*, 1954, **168**, Mar. 12, 625–627). The author discusses three main factors involved in accident prevention in the iron and steel industry : (1) The provision of a safe place of employment ; (2) adoption of safe working procedure, and (3) employment of men who work ' safely '. Examples of works rules are quoted.—G. F.

Presidential Address (S.W.). W. R. D. Jones. (*Trans. Inst. Min. Eng.*, 1954, **113**, May, 739–749). The sociological, technological, economic, and educational backgrounds of the metallurgical industry are broadly reviewed. The relationship between sound metallurgical practice and research is discussed and typical metallurgical problems arising in engineering are considered.—L. E. W.

Modern Light Sources and Their Application in Iron and Steel Works. C. Saatmann. (*Stahl u. Eisen*, 1954, **74**, May 6, 623–628). The working principles of incandescent, vapour discharge and fluorescent lamps, the optical and visual efficiencies of the various types, and their suitability in various places in iron and steel works are discussed.—J. P.

The Lighting of Steelworks. A. Wald. (*Stahl u. Eisen*, 1954, **74**, May 6, 628–635). The circumstances to be taken into consideration when designing the lighting of an iron and steel works, including shops, ancillary plant, traffic ways, and offices are discussed and suitable light sources are described and illustrated.—J. P.

Accidents in the Iron and Steel Industry in 1952. H. Euler. (*Stahl u. Eisen*, 1954, **74**, May 6, 638–649). The results of a statistical enquiry into the nature of the accidents in the West German iron and steel industry in 1952, their causes, places where they occurred, and time lost are given. The investigation sought to correlate accident rate with the spaciousness of plant and number of safety officers and works' doctors. It is concluded that improvement of accident prevention necessitates comprehensive investigations of the cause of accidents.—J. P.

Physics and the Iron and Steel Industry. P. Bastien. (*Mét. Constr. Mécan.*, 1954, **86**, Apr., 273–283). The uses of physics and physical principles in the day to day running of the iron and steel industry and in metallurgical research are discussed.

Separation Plant Removes Sludge from Waste Water. J. E. Culleton. (*Iron Age*, 1954, **173**, Feb. 11, 131–133). A separation system capable of treating 10 million gallons of waste water a day has been built at the Spang-Chalfont plant of the National Supply Co. The plant consists primarily of a Dorr Detritor for separating settled solids, and three primary and three secondary separator basins. It also includes a pump house with scum decanter, scrapers, and skimmers.—A. M. F.

BOOK NOTICES

CHALMERS, BRUCE, and R. KING (Editors). "*Progress in Metal Physics.*" Volume 5. La. 8vo, pp. vii + 324. Illustrated. London, 1954 : Pergamon Press, Ltd. (Price 60*s.*).

Beyond the observation that the high reputation established for itself by the Progress in Metal Physics Series is well upheld by the latest, fifth, volume, no further recommendation of the book will be needed by those acquainted with its predecessors. It consists of five reviews.

In an able *Report on Precipitation* H. K. Hardy and T. J. Heal deal with the fundamental thermodynamic theory, the kinetics of precipitation, the types and distribution of nuclei, grain-boundary effects, X-ray methods of studying precipitation, and other manifold topics of this subject in considerable detail. The treatment is interesting, the writing to the point, and the coverage thorough.

R. Maddin and N. K. Chen, in a contribution entitled *Geometrical Aspects of Plastic Deformation of Metal Single Crystals*, review the work on the basic modes of deformation of metals, with appropriate emphasis on recent work. At the present time, when many ideas on the details of the mechanism of slip-propagation are returning to the melting pot, this review deserves to be studied with particular care. It seems now that a metal made imperfect by " perfect " dislocations is just as untenable an hypothesis as the metal free from lattice faults was found to be long ago. The piecemeal motion of slip bands which, as the authors point out, has been observed on several occasions, seems to show that dislocations too may have their maladies, and in consequence may move along on " crutches." This realization may prove to be of great significance in understanding the basic nature of the mechanisms leading to the observed plasticity in metals.

Fracture in Metals, surveyed by N. J. Petch, is a subject of even greater complexity. Whilst no unified theory has been developed in recent years, nor could be expected, it is nevertheless valuable to have this critical review, particularly as it includes work done since Orowan last surveyed this field, about six years ago. The author makes a brave attempt to account for cleavage fracture on the basis of internal stress concentrations arising from the local piling up of dislocations, but the treatment is not really convincing.

B. T. R. Frost, in *The Structure of Liquid Metals*, gives a lucid account of a subject which may have implications outside the study of liquids proper. He shows clearly that the liquid and the solid states have very much in common, *i.e.*, comparatively small changes in structure occur on melting. It may well be that, resulting from the study of liquids, the hypothesis of a liquid-like layer at grain boundaries in metals subject to high-temperature creep, now long discarded, will before long return in a different cloak looking quite respectable.

Ursula M. Martius's report on *Solidification in Metals* is to some extent complementary to Frost's paper. The work of the pioneers in this field, particularly that of

Tammann and his associates, is surveyed, and the more recent work of the Canadian school is well covered. However, such relevant topics as the attempts to deal statistically with nucleation and solidification from the melt are not considered. In fact, papers written in languages other than German and English are not referred to at all. This is a pity because, in a review of this type, a special endeavour should have been made to draw the reader's attention to work published in journals not likely to be on his, or her, circulation list.—PAUL FELTHAM

MONYPENNY, J. H. G. "*Stainless Iron and Steel.*" Volume 2. "*Microstructure and Constitution.*" Third edition, revised. Edited by Professor F. C. Thompson. 8vo, pp. xii + 330. Illustrated. London, 1954: Chapman and Hall, Ltd. (Price 55*s.*).

This volume of *Stainless Iron and Steel* has been most ably edited by Professor F. C. Thompson from the rough manuscripts and notes of the necessary illustrations which were prepared by the author before his death, and it is a fitting but sad memorial to that great Sheffield metallurgist, the late Mr. J. H. G. Monypenny.

The first volume of this third edition, which appeared some little time ago, discusses stainless iron and steels from the point of view of the industrial user, and this second volume deals with their microstructure and constitution. The volume is intended primarily for metallurgists, but in order that its contents may be useful to engineers and others who have not made a special study of metallography, the author has written in the simplest terms and produced a most readable book.

The first chapter deals with the structure and constitution of the iron–chromium alloys, with and without carbon. This is necessarily a long chapter, as it must be when one remembers that so many industrially useful chromium–iron alloys are found in the range 12% to approximately 30% chromium. In chapter 2 the brittleness produced in high-chromium stainless irons by prolonged heating at 475° C. or thereabouts is given special consideration.

Another long chapter is the third, which deals with the effect of nickel on the structure and properties of chromium steels and with the structure and constitution of iron–chromium–nickel alloys. This chapter also is adequate, and the diagrams and photomicrographs have been particularly well chosen.

Chapter 4 deals with intergranular corrosion in austenitic stainless steels. It will be remembered that a detailed account of this subject was given in volumn No. 1, and to this the reader is referred by the author.

The effect of manganese and of silicon is covered in chapters 5 and 6, respectively, whilst the final chapter deals with the effect of aluminium, molybdenum, tungsten, copper, and cobalt on chromium and chromium–nickel steels.

The indexes (name and subject) cover this second volume only; the first volume carried its own indexes.

In conclusion one cannot do better than to quote from Professor F. C. Thompson's Foreword to the first volume: "... his (Mr. Monypenny's) contribution to our knowledge of the metallography and properties of the high-chromium steels is probably the outstanding contribution made from this country in the whole field of ferrous metallurgy in the last twenty-five years." J. FERDINAND KAYSER.

WILLIS, J. "*Deep Drawing.*" A Review of the Practical Aspects of Professor H. W. Swift's Researches. 8vo. pp. x + 134. Illustrated. London, 1954: Butterworths Scientific Publications. (Price 25*s.*)

The basic principles of the process of deep drawing have been studied very thoroughly by Professor H. W. Swift during the past 17 years. The theoretical nature of his work and the need for further study of the plasticity of metals may account for the fact that engineers have been slow in applying Professor Swift's results to industrial problems.

According to the author, the object of this volume is to present the results of these 17 years of research in a manner easily appreciated by those engaged in the deep drawing industry.

Eight of the ten chapters describe the equipment and experimental procedure of the research, the two remaining chapters discussing the more theoretical aspects of the subject.

Chapter 1 describes the essential details of the programme of work as envisaged in 1937 and gives an account of the experimental equipment built in addition to that obtainable from industry.

In Chapter 2 the author describes the development of the theory of deep drawing, and shows the remarkable agreement between calculated and experimental results. He further indicates that as a result of this it is now possible to forecast the behaviour of a material under specific deep drawing conditions with reasonable accuracy.

The next three chapters are concerned with single-stage and two-stage drawing and the ironing of cylindrical cups. The factors considered are die and punch design, pressure-plate loading, speed of drawing, drawing ratios, effect of work-hardening capacity of material, influence of annealing and the advantages of reverse redrawing. With reference to ironing, particular attention is paid to the effect of die taper and lubrication on strain and residual stresses, and control of wall thickness.

Chapter 6 is an account of work carried out to study the mechanism of shearing of bars and blanks of metals of varying ductility. Factors considered in this work were clearance, speed of punching, and tool design.

In the next chapter deep-drawing lubricants are assessed on the basis of the amount by which they reduce the maximum punch load and their ease of removal from deep-drawn articles. Detailed results of tests are given in the Appendix.

The concluding chapters discuss the effects of sheet quality and punch design on deep drawing, the development of a simulative test for deep-drawing materials and the application of Professor Swift's results to industrial operations.

For expansion of the subject the author indicates references at the end of each chapter. These references, mainly to reports by Professor Swift, are tabulated at the end of the book.

This useful book is well written, nicely printed and bound, profusely illustrated with tables and diagrams, and has been placed on the market at a reasonable price.

L. W. DERRY

NEW PUBLICATIONS

AMERICAN IRON AND STEEL INSTITUTE. "*Directory of Iron and Steel Works of the United States and Canada.*" Twenty-seventh edition. 8vo, pp. xix + 497. New York, 1954 : The Institute.

AMERICAN IRON AND STEEL INSTITUTE. "*Tin Mill Products.*" (Steel Products Manual.) Revised July, 1954. La. 8vo, pp. 28. Illustrated. New York, 1954 : The Institute.

AMERICAN SOCIETY FOR METALS. "'*Metal Progress*' *Data Sheets.*" [Loose-leaf in stiff paper case.] Revised edition. Folio. 192 sheets. Cleveland, Ohio, 1954 : The Society. (Price $6.)

AMERICAN SOCIETY FOR TESTING MATERIALS. "*ASTM Specifications for Steel Piping Materials.*" Pipes, Tubes, Castings, Forgings, Bolting. Prepared by ASTM Committee A–1 on Steel. 8vo, pp. x + 349. Illustrated. Philadelphia, Pa., 1954 : The Society. (Price $3.75)

AMERICAN SOCIETY FOR TESTING MATERIALS and AMERICAN ELECTROPLATERS SOCIETY. "*Specifications and Tests for Electrodeposited Metallic Coatings.*" 8vo, pp. vii + 85. Illustrated. Philadelphia, Pa., 1953 : American Society for Testing Materials. (Price $1.85)

APPLEBY-FRODINGHAM STEEL COMPANY. "*Seraphim.*" 10 in. × 8 in., pp. 87. Illustrated. Scunthorpe, Lincs., 1954: The Company.

BERGMANN, L. "*Der Ultraschall und seine Anwendung in Wissenschaft und Technik.*" Sixth edition. 8vo, pp. 1040. Illustrated. Zurich, 1954 : S. Hirzel Verlag. (Price 68 Swiss francs)

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